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STUDY OF THE RELATION OF THE LENGTH OF KERNEL TO THE YIELD OF CORN. (ZEA MAYS INDENTATA).[1]

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Among corn growers there is a prevalent opinion that length or depth of kernel is a very desirable character in corn (*Zea mays indentata*) and that short kernels indicate deterioration. Rough, dented kernels are usually long and, therefore, this type is given preference by most growers in selecting seed corn, while smoothly dented ears are avoided.

Apparently, the relation of the length of kernel to the yield of corn has not been investigated directly. Some data on this subject, however, have been secured indirectly.

Montgomery [2] compared smooth and rough types of Reid Yellow Dent continuously selected for five years. Comparative yield data were secured for three seasons. The smooth-dented type outyielded the rough-dented type two out of three seasons and averaged 4.4 bushels more per acre. Although no data were presented to show the relative length of the kernels for the two lots of corn, it is probably safe to assume that those of the rough-dented type were the longer because of the correlation between indentation and length of kernels.

The writer [3] reported that smooth- or wrinkle-dented ears outyielded rough ears in ear-to-row tests of several varieties of corn conducted at the Kansas Agricultural Experiment Station.

Williams [4] compared smooth- and rough-dented strains of Clarage corn continuously selected for six years at the Ohio Agricultural Experiment Station and secured an average difference of 1.76 bushels per acre in favor of the smooth type.

Hutcheson and Wolfe [5] compared characters of a group each of high-yielding and low-yielding ears of Boone County White grown in ear-to-row

[1] Contribution No. 19 from Department of Agronomy, Agricultural Experiment Station of Kansas State Agricultural College.

[2] MONTGOMERY, E. G. EXPERIMENTS WITH CORN. Nebr. Agr. Exp. Sta. Bul. 112, p. 23. 1909.

[3] CUNNINGHAM, C. C. THE RELATION OF EAR CHARACTERS OF CORN TO YIELD. *In* Jour. Amer. Soc. Agron., v. 8, no. 3, p. 193. 1916.

[4] WILLIAMS, C. G., and WELTON, F. A. CORN EXPERIMENTS. Ohio Agr. Exp. Sta. Bul. 282, p. 87. 1915

[5] HUTCHESON, T. B., and WOLFE, T. K. RELATION BETWEEN YIELD AND EAR CHARACTERS IN CORN. *In* Jour. Amer. Soc. Agron., v. 10, no. 6, p. 253. 1918.

tests for two seasons. The length of kernel was one of the characters studied. The average length of the kernels in the high-yielding and low-yielding lots were 0.42 and 0.41 inches, respectively, and the yields were 72.5 and 54.8 bushels per acre, respectively. Concerning this point the authors conclude that length of the kernels was a negligible factor in the yields.

Olson, Bull, and Hayes [1] found that smooth and medium smooth ears of Minnesota No. 13 corn slightly outyielded rough ears in ear-to-row tests conducted at the Minnesota Agricultural Experiment Station.

PLAN OF THE EXPERIMENT

An experimental project was put under way at the Kansas Agricultural Experiment Station in 1916 to secure some data concerning the relation of length of kernel to the yield of corn. Commercial White, a medium large variety well adapted to growing on productive soils in eastern Kansas, was used. Three 40-ear lots of corn were selected. One lot was made up of ears with kernels that were relatively short, one of ears with kernels of maximum length, and the third of ears with kernels of medium length. The latter group was practically intermediate between the short- and long-kerneled ones. Since the degree of indentation is usually correlated with length of kernel, this character was taken as an index by which to classify the various ears. Only ears that were almost smooth or "dimple-dented" were selected for the short-kerneled group, while only ears that were sufficiently indented to have kernels with a chaffy crown or with at least an indication of chaffiness at the crown were used for the rough- or deep-kerneled group. In this latter group the endosperm as a rule was not completely filled. The kernels of the intermediate group were "wrinkle-dented," that is, the indentation was sufficient to cause a wrinkling of the epidermis of the kernel over the indented portion. The ears shown in Plate 81 are typical for the group, while Plates 80 and 82 show typical ears of the long- and short-kerneled groups, respectively. These groups are designated as "rough" and "smooth," respectively, while the group with kernels intermediate in length is known as "medium." This last group was practically identical in type and length of kernels with the mean for the Commercial White variety. Kernels of the three types are shown in Plate 83.

The seed for the various groups or types of ears was continuously selected. Smooth ears were selected each season from the progeny of smooth ears, rough ears from the progeny of rough ears, and medium ears from the progeny of medium ears.

In selecting the seed ears, care was taken to secure, if possible, ears that would conform to what is ordinarily considered the standard in seed corn. The ears were well-developed, with uniform kernels and in good seed condition.

[1] OLSON, P. J., BULL, C. P., and HAYES, H. K. EAR TYPE SELECTION AND YIELD IN CORN. Minn. Agr. Exp. Sta. Bul. 174, p. 28. 1918.

Determinations of yield were made in plots consisting of six to eight rows. They were planted in triplicate. The four inside rows only of each plot were harvested for yield. The corn was planted thick in 42-inch drill rows and thinned to a uniform stand of one stalk every 21 inches. No effort was made to control cross pollination between corn of the various types, and undoubtedly the usual amount of cross-fertilization took place.

The yields which are given in Table I are for shelled corn well dried in a heated room where the temperature varied from 60° to 80° F. The probable error was determined by using the formula $p.\ e. = 0.8453 = \frac{1}{n\sqrt{n-1}}$, in which n equals the number of replications.

TABLE I.—*Yields of smooth-, medium-, and rough-dented types of commercial white corn, 1916 to 1919*[1]

Type.	1916	1917	1918	1919	Four-year average.
Smooth	41.7±0.79	41.1±0.50	28.1±0.97	35.2±0.89	36.5±0.78
Medium	41.2± .33	43.9±1.29	23.0± .48	31.1± .35	34.8± .61
Rough	42.1± .86	45.3±1.09	20.3± .14	34.2± .89	35.5± .74

[1] Expressed in bushels per acre of shelled corn.

It will be noted that the smooth-dented type produced the highest 4-year average yield, and that the medium-dented type yielded the least. The data are not very consistent for the 4-year period. There was practically no difference in the yields the first season. In 1917 the rough type produced about 2 bushels more than the medium and about 4 bushels more than the smooth type. This variation appeared to be due entirely to peculiar seasonal conditions at the time the corn was beginning to pollinate. Drought and hot winds prevailed during the last of July and first week in August and greatly damaged corn that flowered during that time. Rains occurred frequently after August 7, making conditions very favorable for corn for the remainder of the season. The smooth type of corn started pollinating two or three days earlier than the other types, and the earliest plants were injured to some extent. Many of the ears were poorly pollinated, especially at the butt. The ears of the medium and smooth type appeared to have been normally pollinated. Since the rough type of corn was slightly the latest of the three types to flower, it more nearly escaped the detrimental effect of the drought and for that reason produced a larger yield.

In 1918 hot, dry weather prevailed throughout the fruiting period of the corn. Under these conditions the smooth type, because of its earlier maturity, had the advantage and produced about 5 bushels more than the medium type and about 8 bushels more than the rough type. The difference in the yields for that season are, no doubt, significant.

In 1919 hot, dry weather prevailed during July, and although the temperature was favorable during August the corn did not make a maximum development because of a deficiency of moisture. The corn was planted much too thick and unfortunately was not thinned until it was 3 or 4 feet high. This no doubt decreased the yields to a considerable extent. The smooth type sustained the greatest injury because of the relatively thick stand for that type. In spite of this handicap the smooth type made the highest yield, although the difference as compared with the rough type is probably not significant. Altogether, the results show that for the conditions of this test a smooth type of corn will yield fully as well as medium or rough types.

The effect of continuous selection for types on the length, circumference, and weight of the ears, number of rows of kernels per ear, the length of kernel, and the percentage of corn to cob were also studied. Data for these characters for the seed ears used for planting the respective type lots each season and for the progeny of each lot were recorded and tabulated.

LENGTH OF EARS

The effect on the length of ears is shown in Tables II and III. It will be noted that the smooth type of ear used for planting consistently averaged longer than those for the other types, and the average length of ear of the progeny of this type was slightly greater. On the other hand, the rough ears were shorter than the others. This same relation between indentation and length of ears is found in the progeny, as shown in Table III.

TABLE II.—*Frequency distribution of ears of various lengths used in planting the type test of Commercial White corn, 1916–1920*

Year and type.	Number of ears having a length (in inches) of—																						Number of ears.	Mean length.
	6	6¼	6½	6¾	7	7¼	7½	7¾	8	8¼	8½	8¾	9	9¼	9½	9¾	10	10¼	10½	10¾	11	11¼		
1916:																								*Inches.*
Smooth											5	5	4	10	3	4	5	2	1	1			40	9.35
Medium											3	5	3	9	8	4	1	5	1	1			40	9.42
Rough											2	5	6	6	3	6	6	2	4				40	9.49
1917:																								
Smooth							3		3	4	4	4	2	2	1	5	3	2		1	1		40	9.16
Medium									2	1	6	7	8	3	3	4	2	2	2				40	9.13
Rough							1	1	1	1	6	5	8	4	3	2	4	2	1			1	40	9.14
1918:									1			2	2	3	4	4	4		4	2			26	9.64
Medium							1		1	2	6	6	4	3	3	1	2	2		1	1		33	8.72
Rough				2		1	3	1	2	6		1	2	2		2	3	2				1	28	8.64
1919:																								
Smooth						1	1	2	2	3	4	3	2	1			1						20	8.42
Medium						1	2	4	2	2	2	2	2	2									20	7.83
Rough	2	1	1	1	2	1			2	2	3	2			1		1						20	7.01
1920:																								
Smooth									2	2	4	5	7	4	6	3	3	1		2	1		40	8.96
Medium								3	4	7	5	8	6	4	2		1						40	8.44
Rough	1		1	2	2	4	9	6	5	4	2	2		1	1								40	7.72
Five-year average:																								
Smooth																								9.11
Medium																								8.72
Rough																								8.40

TABLE III.—*Frequency distribution of ears of various lengths in the progeny of smooth-, medium-, and rough-dented types of Commercial White corn, 1916 to 1919*

Year and type.	Number of ears having a length (in inches) of—																							Number of ears.	Mean length.
	2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8	8½	9	9½	10	10½	11	11½	12				
1916:																									*Inches.*
Smooth	...	...	3	5	5	8	13	19	24	23	38	39	56	70	67	62	42	22	6	2	...			504	8.09
Medium	...	...	10	2	4	9	14	13	23	25	32	41	51	71	66	46	34	11	6	1	...			459	8.07
Rough	...	2	5	3	7	7	11	14	20	18	27	53	49	76	80	42	38	15	1	1	...			469	8.02
1917:																									
Smooth	...	...	3	9	9	18	21	16	18	27	31	28	43	61	66	62	39	19	17	1	2			490	8.14
Medium	...	...	1	4	8	15	12	20	21	23	25	39	54	67	61	66	41	34	11	2	2			506	8.19
Rough	...	...	3	6	10	14	14	24	27	22	36	43	56	63	58	75	37	19	13	10	1			530	8.05
1918:																									
Smooth	...	3	4	11	13	20	28	29	53	79	107	96	94	57	28	12	4	1	...	...	...			639	6.95
Medium	1	5	4	14	13	36	31	53	80	81	104	67	46	21	8	1	...	...	...	...	...			565	6.39
Rough	...	5	10	8	12	20	31	31	73	69	64	81	53	18	7	4	...	2	...	...	...			488	6.53
1919:																									
Smooth	1	1	2	2	10	8	13	23	29	46	61	99	121	129	88	45	19	6	2	...	...			705	7.77
Medium	...	...	2	2	7	14	13	21	35	48	72	114	128	92	60	25	14	2	...	...	...			649	7.57
Rough	...	1	5	9	6	13	20	32	56	67	64	121	107	109	52	23	6	2	...	...	...			692	7.33
Four-year average:																									
Smooth	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...			.....	7.74
Medium	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...			.....	7.56
Rough	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...			.....	7.48

CIRCUMFERENCE OF EARS

As may be seen in Table IV, which shows the circumferences of smooth, medium, and rough types, the rough ears are relatively large in circumference, those of the medium type are intermediate, and the smooth ears are small. The differences are consistent and probably significant. Similar differences for the progeny of these ears occur as shown in Table V.

TABLE IV.—*Frequency distribution of ears of various circumferences used for planting type test of Commercial White corn, 1916–1920*

Year and type.	Number of ears having a circumference (in inches) of—																							Number of ears.	Average circumference.
	5	5¼	5½	5¾	5⅞	5⅞	5¾	5½	6	6⅛	6¼	6⅜	6½	6⅝	6¾	6⅞	7	7⅛	7¼	7⅜	7½	7⅝			
1916:																									*Inches.*
Smooth	...	...	...	...	...	...	...	...	...	...	...	...	4	4	9	11	7	4	1	...	...	...		40	6.84
Medium	...	...	...	...	...	...	...	...	...	...	...	...	2	4	7	7	10	8	2	...	...	...		40	6.91
Rough	...	...	...	...	...	...	...	...	...	...	...	...	...	...	4	2	8	6	7	10	3	...		40	7.16
1917:																									
Smooth	...	...	...	...	...	...	1	1	7	5	10	3	6	5	1	...	...	...	1	...	...	...		40	6.28
Medium	...	...	...	...	...	...	...	...	1	1	5	10	10	3	3	3	3	...	...	1	...	...		40	6.53
Rough	...	...	...	...	...	...	...	...	2	1	3	4	5	3	7	4	2	5	2	...	1	...		40	6.81
1918:																									
Smooth	...	...	...	...	...	...	3	1	8	2	4	3	3	...	2	...	...	...	...	...	...	...		26	6.19
Medium	...	...	...	...	...	...	...	...	2	...	5	4	5	3	5	5	1	1	1	...	...	1		33	6.60
Rough	...	...	...	...	...	...	...	...	...	1	2	...	3	1	5	2	8	1	3	1	...	1		28	7.21
1919:																									
Smooth	...	1	1	3	4	2	2	4	2	1	...	...	...	...	...	...	...	...	...	...	...	...		20	5.96
Medium	...	...	...	1	1	2	3	4	4	2	1	...	1	1	...	...	...	...	...	...	...	...		20	6.16
Rough	...	...	...	...	...	...	...	...	3	4	3	3	3	2	1	1	...	...	...	...	...	...		20	6.55
1920:																									
Smooth	...	...	...	...	4	9	8	13	4	2	...	...	...	...	...	...	...	...	...	...	...	...		40	6.06
Medium	...	...	...	...	...	1	2	7	19	8	2	1	...	...	...	...	...	...	...	...	...	...		40	6.51
Rough	...	...	...	...	...	...	...	...	4	7	15	8	4	1	1	...	...	...	...	...	...	...		40	7.05
Five-year average:																									
Smooth	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...		.....	6.27
Medium	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...		.....	6.54
Rough	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...		.....	6.96

TABLE V.—*Frequency distribution of ears of various circumferences in the progeny of smooth-, medium-, and rough-dented types of Commercial White corn, 1916–1919*

Year and type.	Number of ears having a circumference (in inches) of—																											Number of ears.	Average circumference.
	2¼	2½	2¾	3	3¼	3½	3¾	4	4¼	4½	4¾	5	5¼	5½	5¾	6	6¼	6½	6¾	7	7¼	7½	7¾	8	8¼		
1916:																													*Inches.*
Smooth								1		6	7	11	34	27	39	65	105	81	73	36	10	8	1					504	6.21
Medium								7		6	6	8	15	30	50	80	70	97	37	37	12	3	1					459	6.27
Rough										2	2	15	13	24	27	73	92	89	54	42	22	10	4					469	6.32
1917:																													
Smooth						1	1	1		4	5	16	19	25	54	74	77	93	62	31	16	8	2	1				490	6.22
Medium										3	1	20	12	22	29	44	63	93	82	63	38	27	6	3				506	6.44
Rough						1	1	1	2	4	1	9	15	17	28	39	46	101	84	79	48	30	7	15	2			530	6.57
1918:																													
Smooth								4	10	17	19	54	79	140	107	119	57	23	7	3								639	5.29
Medium				4		3		9	13	16	23	36	54	109	100	114	54	23	4	6								565	5.59
Rough				2	3			8	7	7	11	26	34	87	92	108	47	40	12	3	1							488	5.72
1919:																													
Smooth	1	1		3		1	1	10	9	12	17	38	49	93	106	156	91	78	26	11			2					705	5.79
Medium				1	1	3	2	3	1	7	11	26	34	99	66	132	92	103	38	22	4	2	2					649	5.94
Rough		1	2		1	2	1	4	4	8	6	20	19	56	47	90	104	143	75	72	27	12	8	1				692	6.21
Four-year average:																													
Smooth																													5.88
Medium																													6.06
Rough																													6.21

WEIGHT OF EARS

The average weight of the seed ears of the three types used in planting varied but little after the first season. The data given in Table VI show that the smooth ears averaged slightly less than the medium, and the rough type slightly heavier. The differences are not entirely consistent and probably are not great enough to be considered significant. The data for the progeny as given in Table VII also show that there is but little difference in the average weight of the ears of the various lots.

TABLE VI.—*Frequency distribution of ears of various weights used in planting type test of Commercial White corn for 1916–1920*

Year and type.	Number of ears weighing (in grams)—											Number of ears.	Average weight.
	175 to 200.	200 to 225.	225 to 250.	250 to 275.	275 to 300.	300 to 325.	325 to 350.	350 to 375.	375 to 400.	400 to 425.	425 to 450.		
1916: [a]													*Gm.*
Smooth													
Medium													
Rough													
1917:													
Smooth			1	1	6	8	10	7	6	1		40	321
Medium					1	9	15	11	3	1		40	330
Rough				3	3	3	9	10	7	3	2	40	361
1918:													
Smooth			1	4	7	7	3	3	1			26	306
Medium		1		3	5	12	5	4	2	1		33	313
Rough		2	2	5	7	2	3	4	3			28	300
1919:													
Smooth		4	6	7	3							20	250
Medium		4	7	4	2	1	1	1				20	257
Rough	2	2	3	6	4	2	1					20	260
1920:													
Smooth			7	13	6	6	4	3	1			40	286
Medium		1	3	6	11	11	6	2				40	295
Rough	1	1	3	5	13	9	5	3				40	295
Five-year average:													
Smooth													290.9
Medium													299.0
Rough													304.2

[a] No data.

TABLE VII.—*Frequency distribution of ears of various weights in the progeny of smooth-, medium-, and rough-dented types of corn, 1916–1919*

Year and type.	Number of ears weighing (in grams)—										Number of ears.	Average weight.
	0 to 50.	50 to 100.	100 to 150.	150 to 200.	200 to 250.	250 to 300.	300 to 350.	350 to 400.	400 to 450.	450 to 500.		
												Gm.
1916:												
Smooth	14	37	36	56	68	90	105	74	22	2	504	257.1
Medium	15	27	28	62	66	95	89	68	9	.....	459	252.6
Rough	4	37	31	37	72	106	107	54	19	2	469	261.5
1917:												
Smooth	10	40	59	62	87	106	72	39	15	.....	490	228.3
Medium	17	43	47	54	95	106	91	47	11	.....	506	233.5
Rough	16	43	48	67	90	92	113	42	19	.....	530	239.8
1918:												
Smooth	38	73	119	218	154	34	3	.....	.....	.....	639	163.4
Medium	59	86	125	155	119	19	4	.....	.....	.....	565	148.1
Rough	42	65	105	157	91	25	3	.....	.....	.....	488	153.4
1919:												
Smooth	23	57	91	120	182	173	49	7	.....	.....	705	202.4
Medium	15	41	80	138	191	130	51	3	.....	.....	649	206.5
Rough	22	55	79	135	136	160	89	14	2	.....	692	213.6
Four-year average:												
Smooth	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	210.3
Medium	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	209.9
Rough	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	217.9

NUMBER OF ROWS OF KERNELS PER EAR

The data for number of rows of kernels per ear for the corn used in planting the type test were not determined the first season. The results for 1917, 1918, 1919, and 1920 are given in Table VIII. The data show that the mean number of rows per ear has remained practically stationary in the medium type, decreased in the smooth type, and increased in the rough type. Data for the progeny show similar though somewhat smaller differences.

TABLE VIII.—*Frquency distribution of ears with various number of rows of kernels used for planting type test of Commercial White corn for 1917–1920*

Year and type.	Number of ears with—						Number of ears.	Average number of rows.
	12 rows.	14 rows.	16 rows.	18 rows.	20 rows.	22 rows.		
1917:								
Smooth	10	21	8	1	.....	.....	40	14.0
Medium	.....	17	19	3	1	.....	40	15.4
Rough	.....	11	20	7	2	.....	40	16.0
1918:								
Smooth	8	12	5	1	.....	.....	26	13.9
Medium	1	13	15	2	2	.....	33	15.5
Rough	.....	6	11	9	2	.....	28	16.5
1919:								
Smooth	4	13	2	1	.....	.....	20	14.0
Medium	1	7	10	2	.....	.....	20	15.3
Rough	.....	3	7	7	3	.....	20	17.0
1920:								
Smooth	8	25	5	2	.....	.....	40	14.1
Medium	3	13	20	4	.....	.....	40	15.3
Rough	.....	6	14	14	5	1	40	17.1
Four-year average:								
Smooth	.....	.....	.....	.....	.....	.....	.....	14.0
Medium	.....	.....	.....	.....	.....	.....	.....	15.4
Rough	.....	.....	.....	.....	.....	.....	.....	16.7

TABLE IX.—*Frequency distribution of ears with various numbers of rows of kernels in the progeny of smooth, medium, and rough types of corn, 1916–1919*

Year and type.	Number of ears with—											Number of ears.	Average number of rows.
	6 rows.	8 rows.	10 rows.	12 rows.	14 rows.	16 rows.	18 rows.	20 rows.	22 rows.	24 rows.	26 rows.		
1916:													
Smooth	.....	2	17	114	179	124	45	20	2	1	.....	504	14.5
Medium	.....	.....	9	83	152	142	55	17	1	.....	.....	459	14.9
Rough	.....	.....	5	66	171	138	70	14	3	1	1	469	15.1
1917:													
Smooth	.....	1	7	112	183	114	47	12	3	1	.....	490	14.2
Medium	.....	.....	14	69	170	157	71	18	6	1	.....	506	15.0
Rough	.....	.....	13	89	165	160	83	45	4	1	.....	530	15.0
1918:													
Smooth	.....	.....	27	155	253	150	44	9	1	.....	.....	639	13.9
Medium	.....	.....	25	109	209	155	57	11	1	.....	.....	565	14.5
Rough	.....	.....	20	81	181	143	50	9	2	.....	.....	488	14.7
1919:													
Smooth	3	11	27	147	295	171	44	6	1	.....	.....	705	14.1
Medium	1	6	21	98	230	208	70	14	1	.....	.....	649	14.7
Rough	4	4	11	81	206	219	119	38	8	1	1	692	15.4
Four-year average:													
Smooth	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	14.2
Medium	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	14.8
Rough	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	15.1

LENGTH OF KERNELS

The data presented in Table X show that the length of kernels of the ears selected for planting have averaged 0.422 inch for the smooth type, 0.473 for the medium, and 0.512 for the rough. Continuous selecting of smooth, medium, and rough ears appears not to have changed the relative length of the kernels during four generations, as shown in Table XI. In other words, there has been a marked regression toward the mean of the variety, which probably indicates that the length of the kernel is influenced more by environment than the other characters that have been studied.

TABLE X.—*Frequency distribution of ears with various lengths of kernels of Commercial White corn used in planting, 1916–1919*

Year and type.	Number of kernels having a length (in inches) of—								Number of ears.	Average length.
	11/32	12/32	13/32	14/32	15/32	16/32	17/32	18/32		
1916:										*Inches.*
Smooth	.....	4	19	17	.....	.....	.....	.....	40	0.416
Medium	.....	.....	.....	15	16	9	.....	.....	40	.478
Rough	.....	.....	.....	.....	.....	12	15	13	40	.532
1917:										
Smooth	1	10	15	10	2	2	.....	.....	40	.413
Medium	.....	1	1	5	12	17	3	1	40	.481
Rough	.....	.....	.....	4	10	19	4	3	40	.494
1918:										
Smooth	.....	2	8	8	6	2	.....	.....	26	.435
Medium	.....	.....	1	10	10	11	1	.....	33	.470
Rough	.....	.....	2	4	9	10	3	.....	28	.487
1919:										
Smooth	.....	2	6	8	4	.....	.....	.....	20	.428
Medium	.....	.....	3	2	12	2	.....	1	20	.464
Rough	.....	.....	.....	.....	1	12	2	5	20	.517
Four-year average:										
Smooth	.....	.....	.....	.....	.....	.....	.....	.....	.....	.422
Medium	.....	.....	.....	.....	.....	.....	.....	.....	.....	.473
Rough	.....	.....	.....	.....	.....	.....	.....	.....	.....	.512

TABLE XI.—*Frequency distribution of ears of various lengths of kernels in the progeny of smooth, medium, and rough corn, 1916–1919*

Year and type.	Number of kernels having a length (in inches) of—													Number of ears.	Average length of kernel.
	7/32	8/32	9/32	10/32	11/32	12/32	13/32	14/32	15/32	16/32	17/32	18/32	19/32		
1916:															*Inches.*
Smooth	1	3	2	27	39	139	143	110	28	11	1	.....	.....	504	0.383
Medium	....	7	5	12	32	97	115	116	34	36	4	1	.....	459	.407
Rough	....	1	3	17	27	70	105	128	48	56	6	5	3	469	.411
1917:															
Smooth	2	6	14	44	84	166	88	57	18	7	2	2	.....	490	.371
Medium	6	9	18	47	63	150	92	65	35	16	5	.....	.....	506	.385
Rough	9	17	26	50	81	155	86	62	22	17	5	.....	.....	530	.375
1918:															
Smooth	7	17	35	83	113	195	94	59	26	5	1	1	.....	639	.358
Medium	15	12	18	37	74	182	95	65	49	16	2	1	.....	565	.379
Rough	13	5	15	41	35	145	63	75	41	41	5	8	.....	488	.385
1919:															
Smooth	1	17	18	51	81	137	124	134	71	54	16	1	.....	705	.400
Medium	2	1	17	36	58	120	133	147	79	50	3	2	.....	649	.409
Rough	....	7	7	24	51	82	135	177	116	66	23	4	.....	692	.425
Four-year average:															
Smooth	....	....	....	....	....	....	....	....	....	....	....	....	....	....	.378
Medium	....	....	....	....	....	....	....	....	....	....	....	....	....	....	.395
Rough	....	....	....	....	....	....	....	....	....	....	....	....	....	....	.399

TRANSMISSION OF INDENTATION IN THE PROGENY OF SMOOTH, MEDIUM, AND ROUGH TYPES OF CORN

The number of ears of each type in the progeny of each type is shown in Table XII. The results are illustrated in figure 1 and Plates 84 to 87. The data show that there was a marked tendency for the smooth, medium,

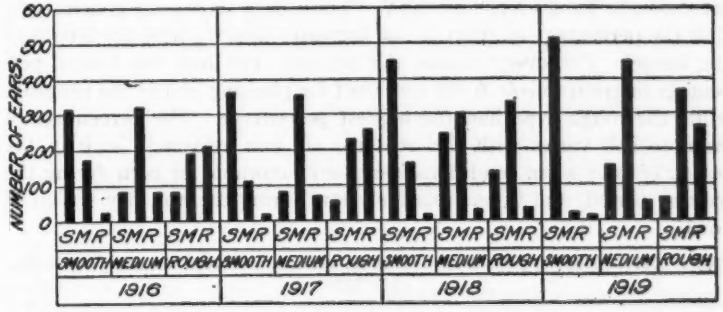


FIG. 1.—Transmission of the character of indentation in the progeny of continuously selected smooth, medium, and rough types of corn. The columns show the number of ears of the respective types in the progeny of smooth-, medium-, and rough-dented Commercial White corn for each season.

and rough types to transmit their respective type characters to the progeny each season. This fact is most apparent in the smooth type. For each successive season the proportion of corn of the smooth type in the progeny increased over that for the preceding season. There was very little variation in the medium type except for the dry season of 1918. The percentage of ears of the smooth type that season was greatly increased, apparently because of the effect of drought on the development of the ears. This also occurred in 1919, but not to the same extent.

The rough type failed to produce as high a percentage of ears of the parent type as did the others. This was especially true in the dry seasons of 1918 and 1919. It seems, therefore, that seasonal conditions, especially drought, have a decided effect on the indentation.

TABLE XII.—*Transmission of the character of indentation in the progeny of smooth, medium, and rough types of corn, 1916–1919*

Year and type.	Number of ears in the progeny.		
	Smooth.	Medium.	Rough.
1916:			
Smooth	315	72	75
Medium	172	316	190
Rough	17	71	204
1917:			
Smooth	364	83	48
Medium	114	356	226
Rough	12	67	246
1918:			
Smooth	454	241	130
Medium	160	301	325
Rough	9	25	32
1919:			
Smooth	515	152	61
Medium	186	450	368
Rough	4	47	263

RATIO OF GRAIN TO COB

The relation between smoothness of ears and the ratio of grain to cob are shown in Tables XIII and XIV. These data show quite conclusively that the percentage of grain to cob increases directly with the length of the kernel. For every season the smooth type had the lowest percentage of grain to cob in the ears used for planting and in the progeny, while the rough type had the highest percentage. The percentage of grain to cob varies with the seasons. It was relatively high in the season of 1917 when conditions were very favorable for corn during the fruiting period, and it was relatively low during the hot, dry season of 1918.

TABLE XIII.—*Ratio of grain to cob in smooth, medium, and rough ears used for planting 1916–1920*

Year and type.	Percentage of grain to cob.	Year and type.	Percentage of grain to cob.
1916:		1919:	
Smooth	77.9	Smooth	76.9
Medium	79.5	Medium	79.0
Rough	80.9	Rough	81.2
1917:		1920:	
Smooth	82.96	Smooth	80.1
Medium	83.70	Medium	82.3
Rough	83.93	Rough	84.0
1918:		Five-year average:	
Smooth	80.8	Smooth	79.7
Medium	81.6	Medium	81.2
Rough	82.4	Rough	82.5

TABLE XIV.—*Percentage of grain to cob for the progeny of smooth, medium, and rough ears, 1916–1919*

Year and type.	Percentage of grain to cob.	Year and type.	Percentage of grain to cob.
1916:		1919:	
Smooth	77.9	Smooth	76.9
Medium	79.5	Medium	79.0
Rough	80.5	Rough	81.2
1917:		Four-year average:	
Smooth	80.7	Smooth	78.2
Medium	81.4	Medium	79.7
Rough	82.3	Rough	81.0
1918:			
Smooth	77.5		
Medium	78.9		
Rough	80.0		

PRACTICAL APPLICATION

Because of the popular opinion that smoothness of ears is an indication of deterioration, the results of this study are of practical interest. Smooth corn has several advantages over medium or rough. Every corn grower knows that the smooth type is much to be preferred at husking time. This type is not so subject to damage from molds and other fungi following injury to the ears from the corn earworm. The latter factor is often an important one, since moldy corn is dangerous to feed. Rough ears, because of the length of kernel and circumference of the ears, do not dry out as rapidly as the smooth type, and for this reason they are more likely to be low in vitality as a result of freezing. Smooth kernels are less likely to rot when conditions for germination are unfavorable. It would seem, therefore, that the corn grower should not hesitate to select smooth ears. It may be well to select slightly rougher ears than are desired in the progeny, since there appears to be a decided tendency to vary toward the smooth type. It is also well to do this in order to avoid a hard, flinty type of kernel that would be unsatisfactory for feeding without grinding.

CONCLUSIONS

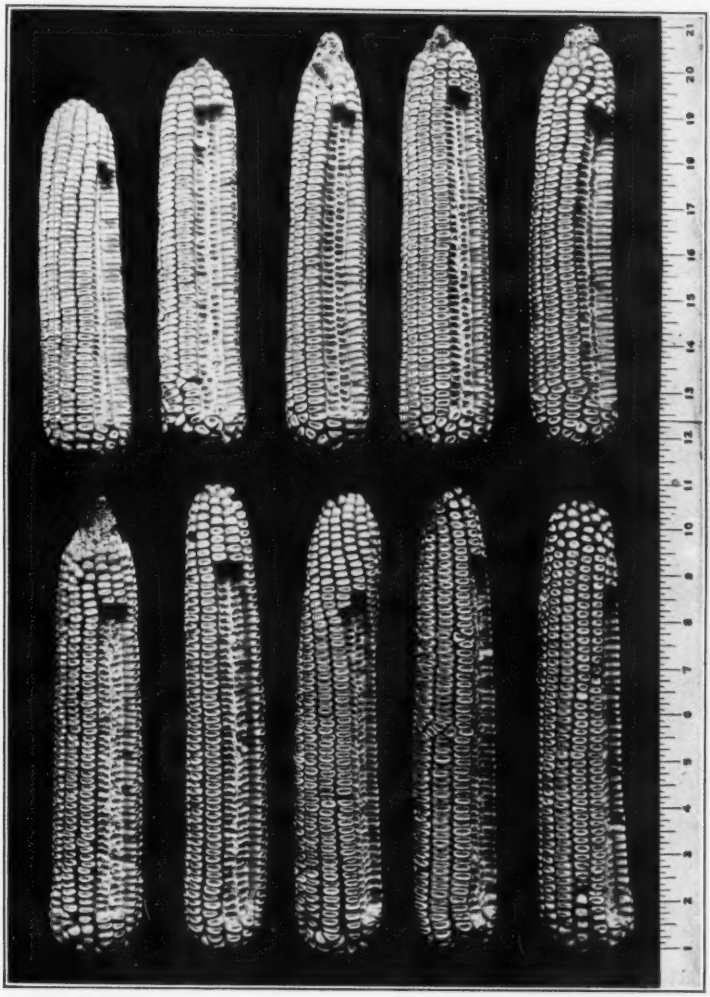
The popular opinion that smoothness in corn is an indication of deterioration and reduced yielding capacity appears to be erroneous. In the experiments reported the smooth type yielded as well as the medium and rough types on the average and indicated that under adverse conditions it will yield better.

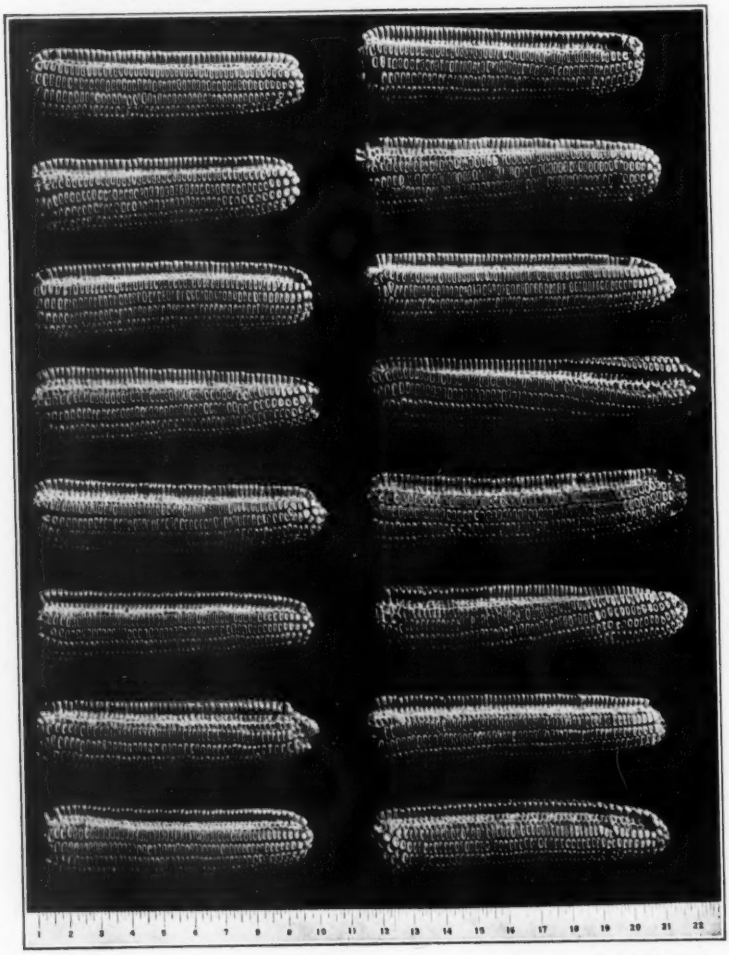
Continuous selection of smooth and rather short kernels for four generations increased the average length of the ears, decreased the circumference, slightly decreased the weight, decreased the number of rows per ear, and decreased the length of the kernel and the percentage of shelled grain.

On the other hand, continuous selection of rough and rather long kernels decreased the average length of the ear and increased the circumference but had no significant effect on the weight of ears, the number of rows per ear, the length of the kernel, or the percentage of grain.

PLATE 80

Typical ears of the smooth-dented or short-kerneled type selected from Commercial White corn.





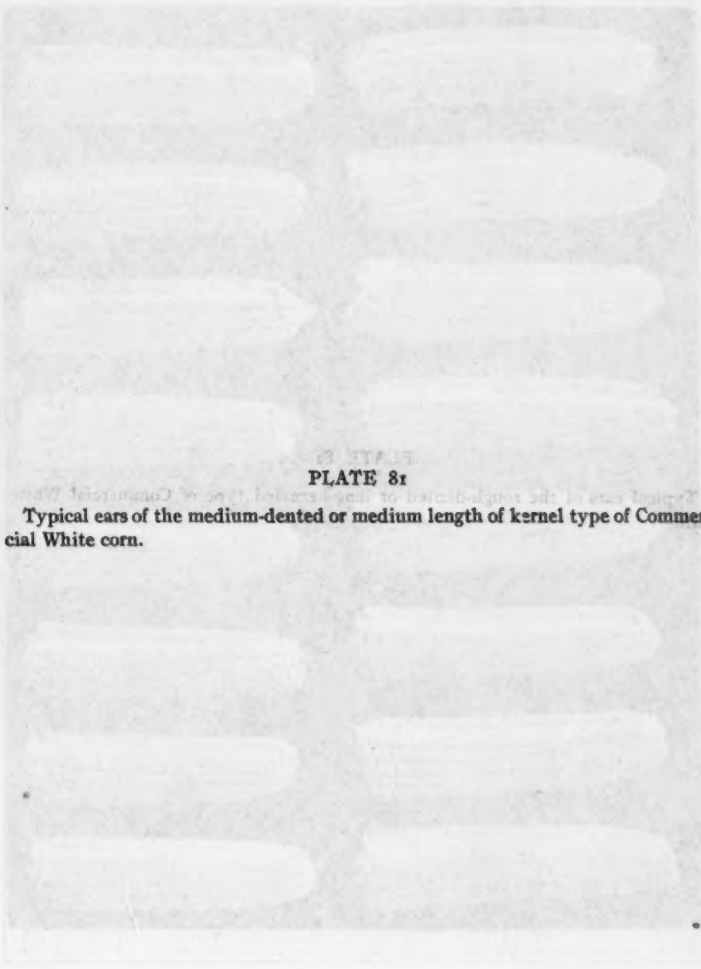


PLATE 81

Typical ears of the medium-dented or medium length of kernel type of Commercial White corn.

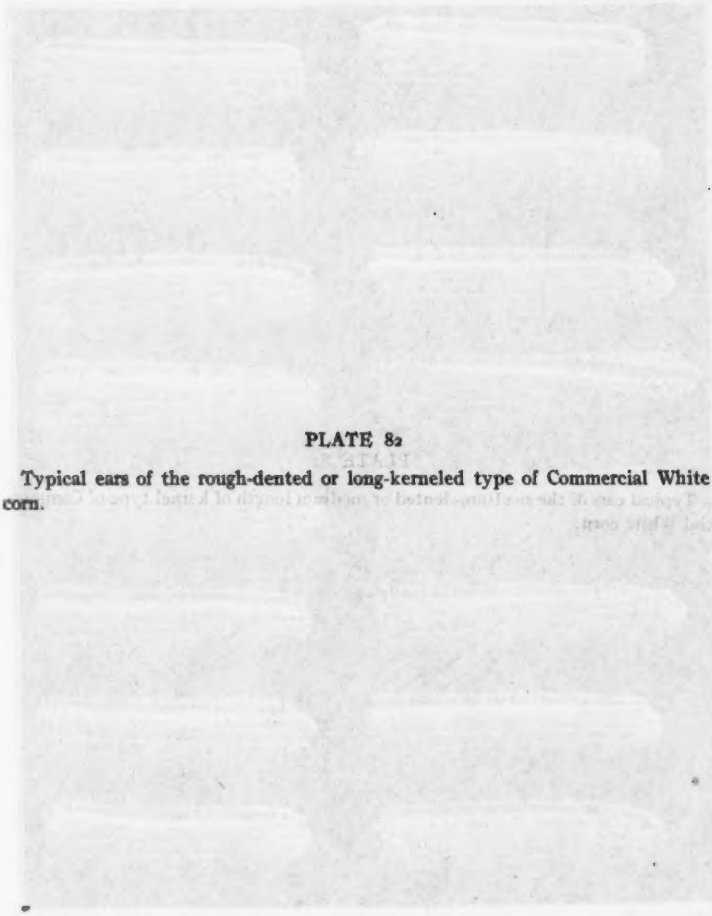
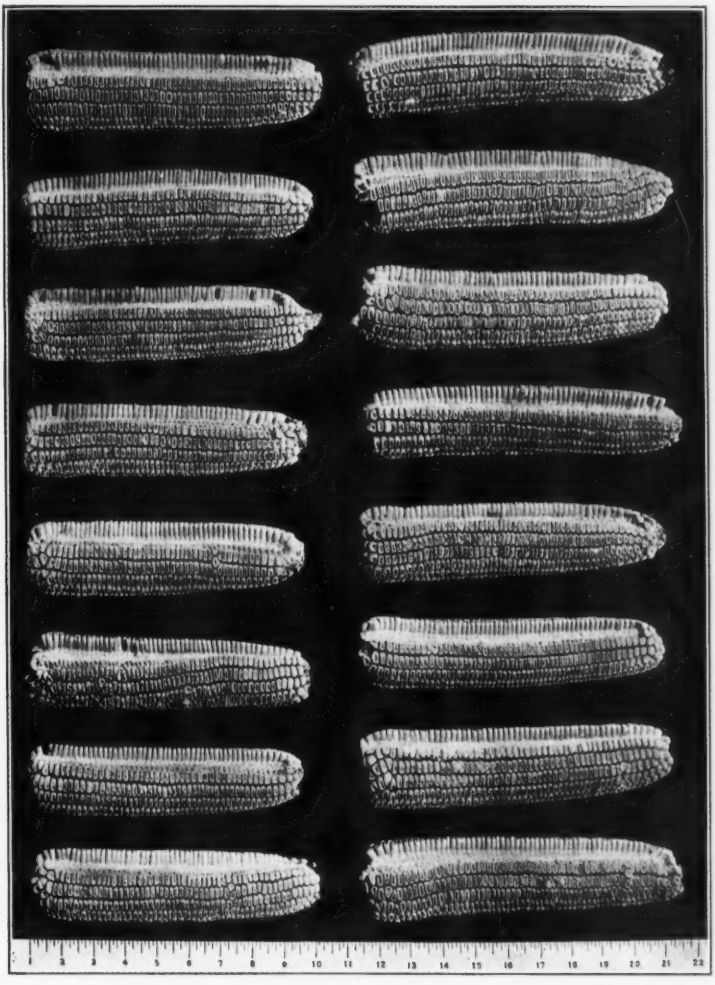
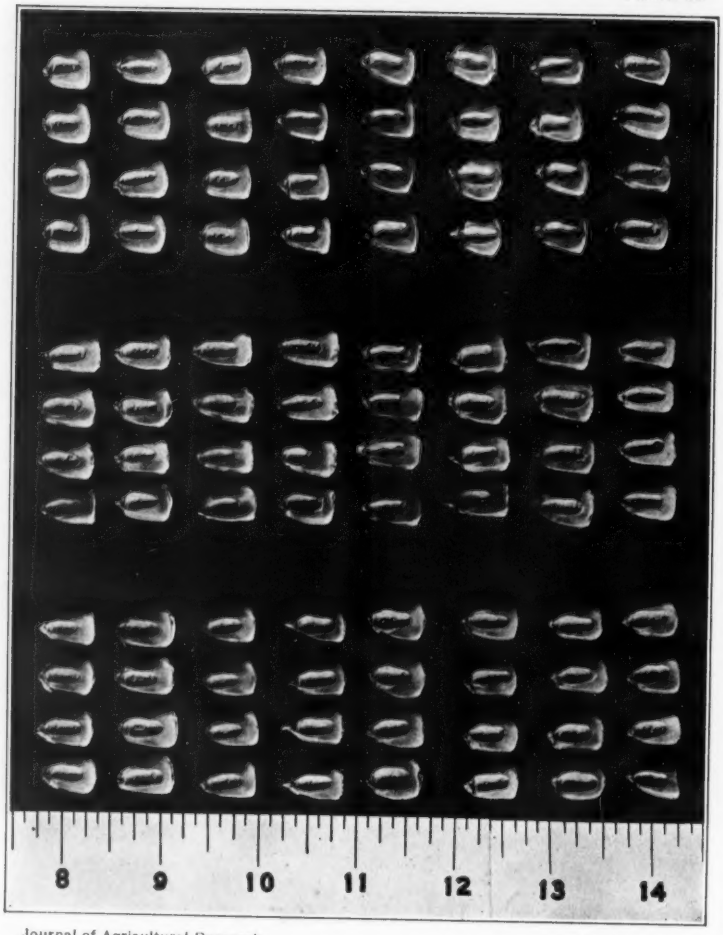


PLATE 82

Typical ears of the rough-dented or long-kerneled type of Commercial White corn.

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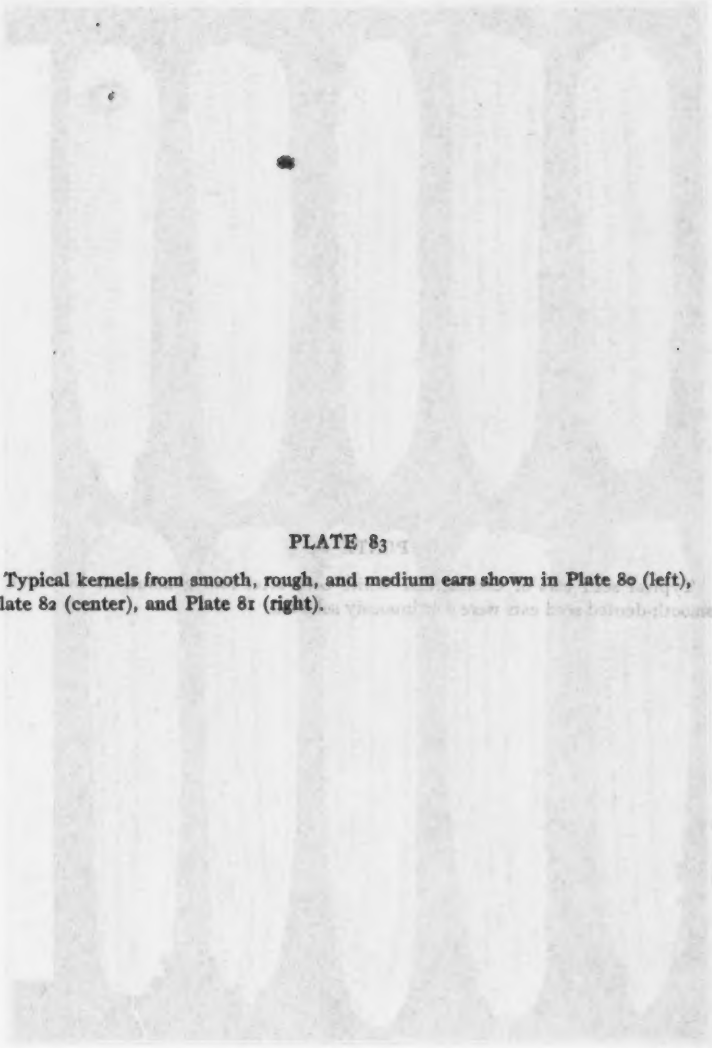
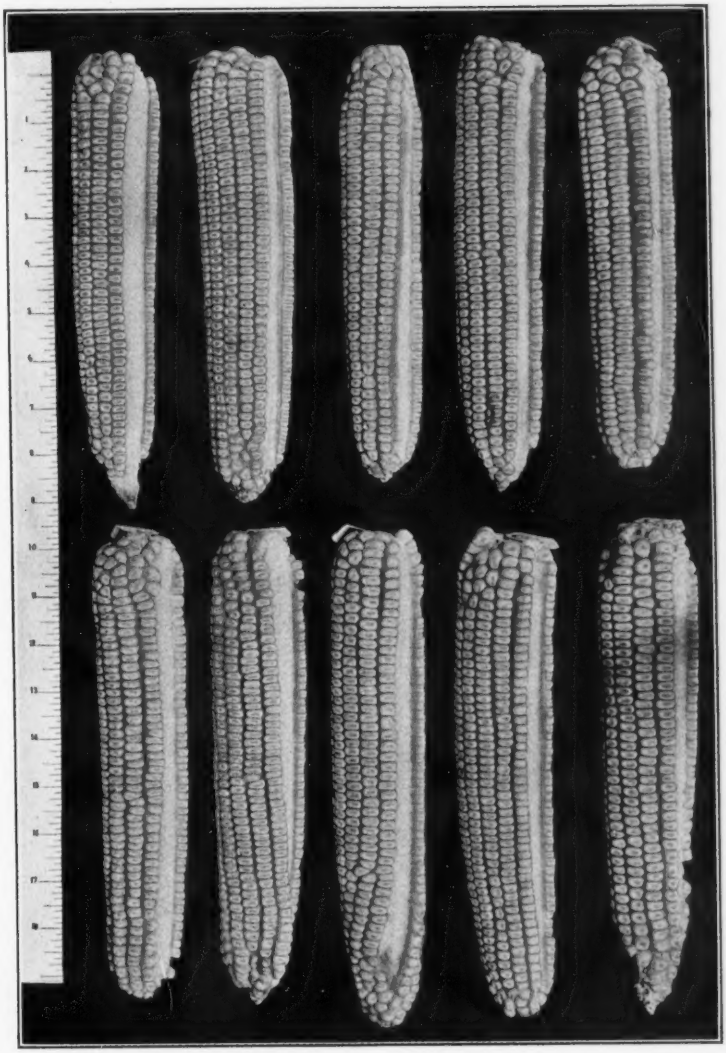


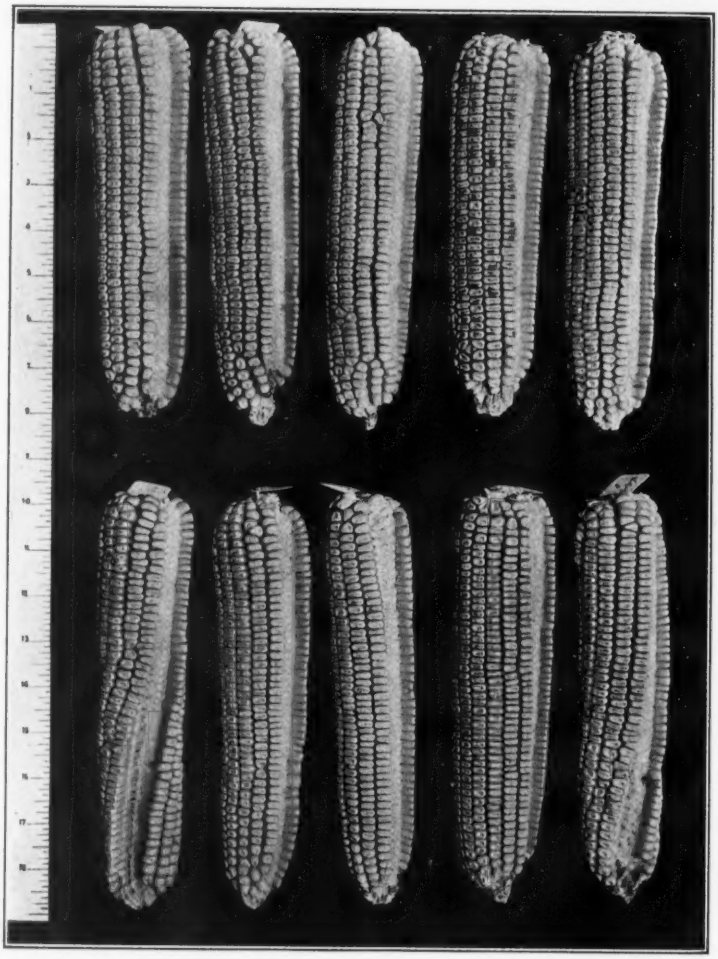
PLATE 83

Typical kernels from smooth, rough, and medium ears shown in Plate 80 (left), Plate 82 (center), and Plate 81 (right).

PLATE 84

Typical seed ears of Commercial White corn after four generations in which smooth-dented seed ears were continuously selected.





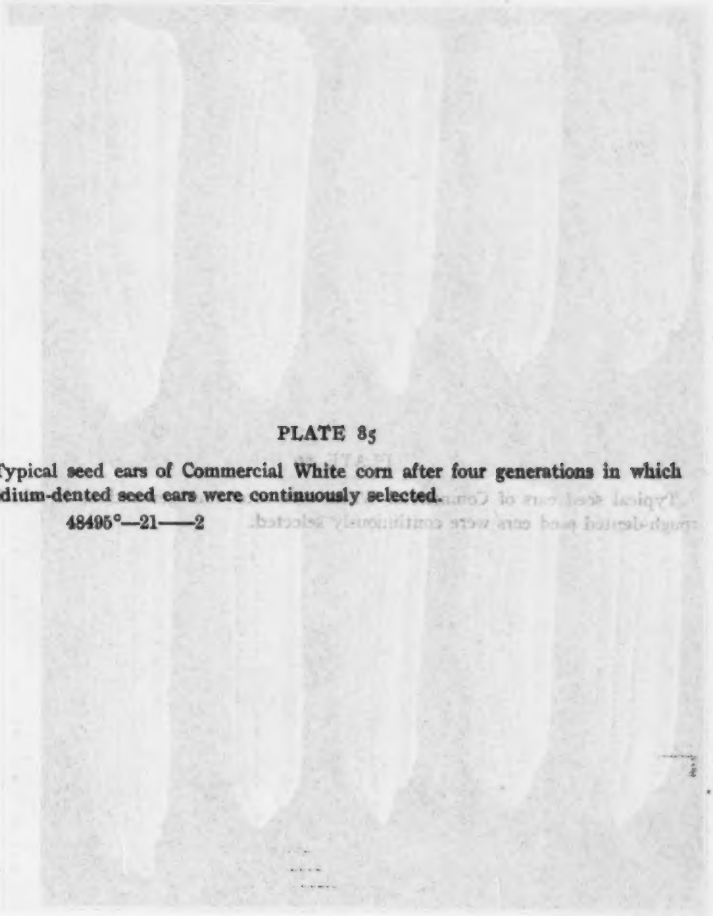


PLATE 85

Typical seed ears of Commercial White corn after four generations in which medium-dented seed ears were continuously selected.

48495°—21——2

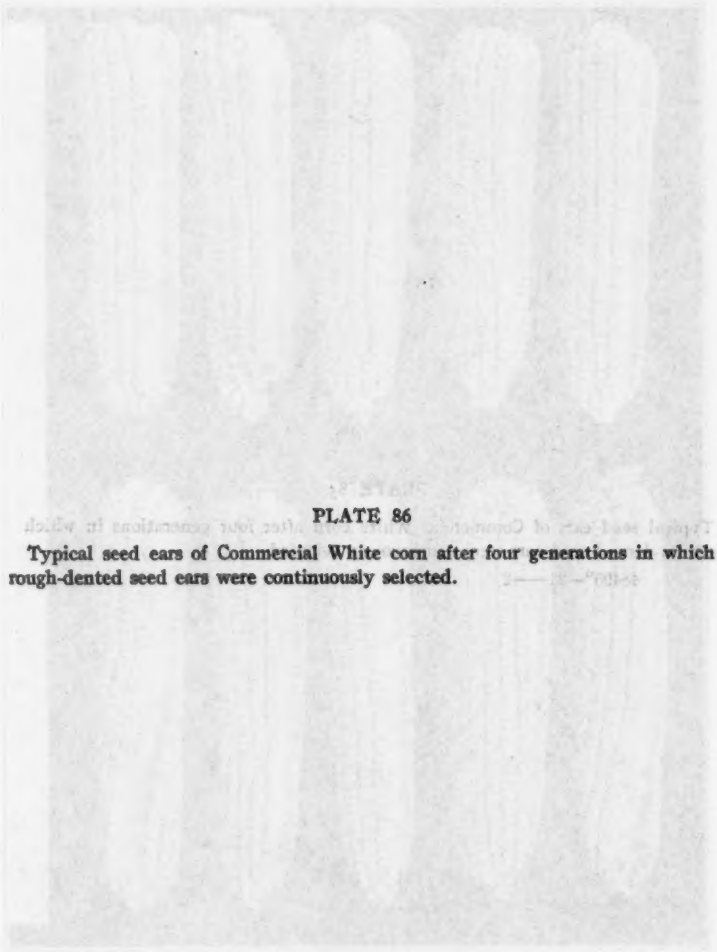
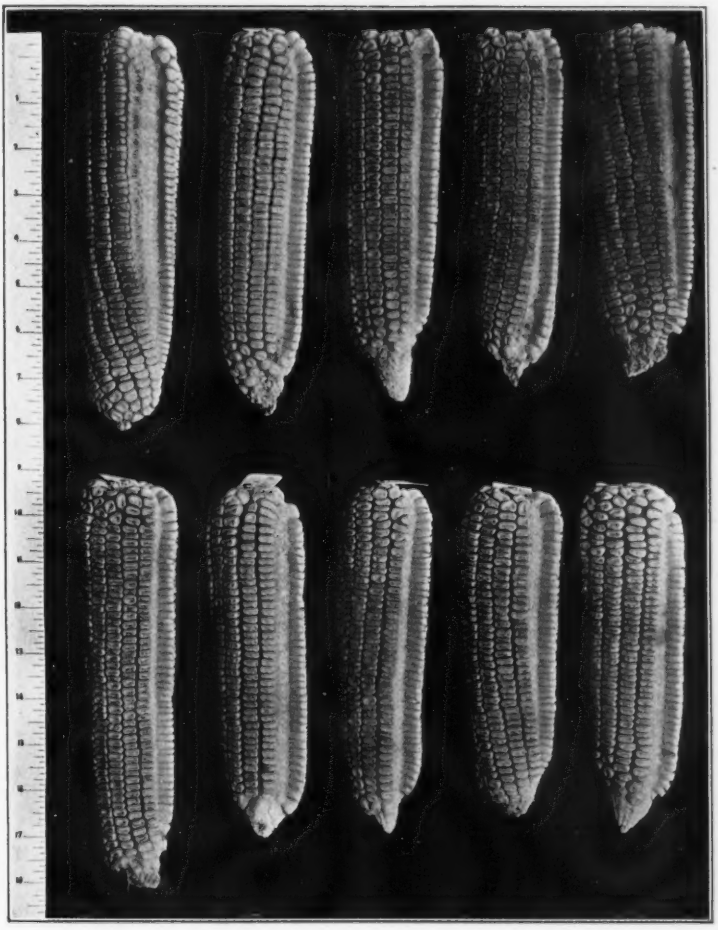


PLATE 86

Typical seed ears of Commercial White corn after four generations in which rough-dented seed ears were continuously selected.



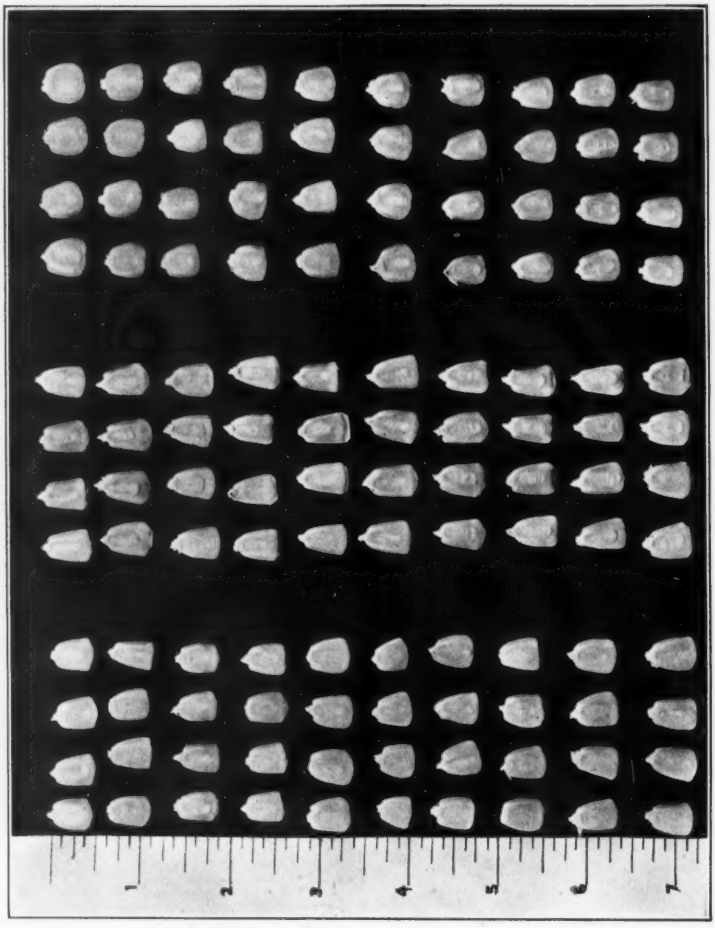


PLATE 87

Typical kernels from the smooth-, rough-, and medium-dented seed ears shown in Plate 85 (left), Plate 86 (center), and Plate 85 (right), respectively.

DISTINGUISHING CHARACTERS OF THE LARVAL STAGES OF THE OX-WARBLES HYPODERMA BOVIS AND HYPODERMA LINEATUM, WITH DESCRIPTION OF A NEW LARVAL STAGE

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Since it has been unquestionably shown that the two species of Hypoderma are of great economic importance on account of the injuries caused by the larvæ or grubs in perforated hides, the loss of flesh, and diminished milk production of cattle, it is important that more be known about their morphology in order that they may be distinguished readily in all stages.

The purpose of the present paper is to show the value of the posterior stigmal plates and other characters for differentiating the four larval stages previously known and to describe a new larval stage of *Hypoderma lineatum* De Villiers. In making a careful study of the larvæ it was found that very reliable characters existed for distinguishing larvæ of *H. lineatum* and *H. bovis* De Geer. Separation of these two species in the last two stages was found to be easy by comparison of the form and structure of the posterior stigmal plates. The character of the spiny armature, which was first described by Brauer and which has been entirely relied upon by all investigators up to the present time for the distinguishing of the species, is good only for the last or fifth larval instar; while the characters of the stigmal plates permit, with absolute certainty, the differentiation of the fourth as well as the fifth larval instar.

The stigmal plate is a complicated structure, and it will be considered here only in so far as it is of importance in differentiating the two species in question. J. C. H. De Meijere (*8*)[2] has given an admirable description of the details of structure and functions of the posterior stigmal plates of *H. bovis*.

The plates vary greatly in the different stages of development and to a considerable extent in the same stage. There may even be a marked variation between the two spiracles on the same specimen. Variable as they may appear, however, there are always certain definite associated characters which can be relied upon for each species.

[1] The author wishes to express his thanks and appreciation to Mr. F. C. Bishopp, Entomologist, Investigations of Insects Affecting the Health of Animals, Bureau of Entomology, for his help and suggestions in many ways in carrying out these studies; to Mr. H. B. Bradford, Artist, Bureau of Entomology, who executed the drawings of figures 5 to 23, inclusive; and to Mr. R. W. Wells, Scientific Assistant, Bureau of Entomology, for valuable material collected in various parts of the United States.

[2] Reference is made by number (italic) to "Literature cited," p. 456–457.

The anterior spiracles located above and on either side of the mouth are described in detail by Carpenter and Pollard (*3*). These organs, in so far as they have been studied, do not lend sufficient definite characters to be of any material value in differentiating the two species.

In order to arrive at an interpretation of the structure of the posterior stigmal plates, so far as is necessary in the present paper, it will be best to consider the last or fifth larval instar.

If a transverse section of the stigmal plate is viewed with a medium-power microscope it will be seen that the plate is composed of three layers which may be designated as the external, the middle, and the internal. The internal part, often visible in newly molted specimens viewed from the external surface with a deep focus, is composed essentially of a series of irregular, chitinous, plate-like structures which vary greatly in outline but are fairly constant in number for each species. These radiate from the tracheal chamber. The middle layer is composed of a series of tubes or stems that arise from the internal plate-like structures and terminate at the surface in a disk, the margin of which is most heavily chitinized, giving a ring-like appearance. This is surrounded by supporting tissues. Surface views of the plate often show the separation and even the form of the internal series of structures by light sutures dividing these disks or ring-like structures into sections similar to those in the internal layer, but not so clearly defined.

From surface views of the plates they naturally vary according to the size and number of the disks or ring-like structures, and it is this variation which is so useful in differentiating the larvæ of the fourth instar.

Brauer (*1*, *p. 125*) mentions only three larval stages of *H. bovis*. The first stage he regards as unknown and calls the two large spiny stages appearing in the backs of cattle the second and third. In 1888, Hinrichsen (*6*), a veterinarian in Husum in South Jutland, published an article in which he related his findings of another stage of Hypoderma larvæ in the spinal cavity of cattle. This is the first mention made of what had so far been considered as the first-stage larva or the stage which Brauer regarded as unknown.

In 1890, Cooper Curtice (*4*), of the Bureau of Animal Industry, United States Department of Agriculture, first noted the appearance of a similar stage of a Hypoderma larva which he terms *H. bovis*, appearing in the esophageal walls, under the pleura near the eleventh rib and in the subcutaneous tissue of the backs of cattle. He speaks of this stage as the first-stage larva. This stage was unarmed with spines and unlike the two larger armed stages described by Brauer in the backs of cattle. This was really not the first-stage larva, as C. V. Riley (*9*), of the Bureau of Entomology, in 1891, first described the real first-stage larva of *H. lineatum* which he obtained from the egg just before hatch-

ing. Riley found that this young or first-stage larva was armed heavily with spines and was wholly unlike the much longer, apparently unarmed larva found by Curtice in the esophageal walls or by Hinrichsen in the spinal cavity. Riley states that—

> In the absence of any knowledge of an intermediate form, the larva found in the esophagus may be considered as the second stage

and designates the two stages found by Brauer as the third and fourth stages. In 1914, Gläser (*5*, *10*), of Germany, and Carpenter, Hewitt, and Reddin (*2*), of Ireland, first observed the first-stage larva of *H. bovis* outside of the egg. The three last-named investigators give a complete illustration of the first-stage larva as it appears after emergence from the eggshell.

So far the four larval stages mentioned above have been the only ones known, but during recent studies by the writer for the purpose of determining distinguishing characters of all the larval stages of both species the fact was revealed that there is another stage to be found in the esophagus of the host. This new stage is unlike the small, heavily armed larva that hatches from the egg or the larger, spineless larva that is later found in the esophagus or on the back before molting to the next spiny stage, formerly known as the third stage. Careful examinations were made of a large series of larvæ of all sizes measuring up to 14 mm. in length taken from esophagi and others measuring as high as 16 mm. extracted from the backs of cattle shortly after the hole through the hide had been completed but before the molt to the next larger or spiny stage had taken place. These studies conclusively revealed that the smaller larvæ in the esophagus are not of the same stage as some of the large larvæ measuring from 11 to about 14 mm. in the esophagus and all of those that later appear in the subcutaneous tissues of the back. Since the smaller armed larva found in the esophagus differs from the first stage hatching from the egg it must be considered the second stage, the large, spineless larva in the esophagus and in the back the third stage, and the following two armed stages as the fourth and fifth. There still remains, of course, the possibility of the occurrence of other intermediate stages, especially between the first stage and the first one found in the esophagus. The third or unarmed stage that reaches the back molts from the smaller or armed second stage before it leaves the esophagus, or possibly, in some instances at least, on its journey to the back. Many specimens from gullets as long as 14 mm. are still in the second stage while others similarly located and measuring as low as 11 mm. are in the third stage. The early investigators overlooked the unarmed stage in the back and concluded that there were only two stages encysted under the skin. This oversight was probably due to the fact that at the time the unarmed larva has punctured the hide and is undergoing the molt to the next stage the swelling or the

"bump" of the newly encysted larva is so slight that it remains unnoticed even by a close observer, and later when more growth has taken place and the swelling has enlarged sufficiently to become plainly noticeable the larva is already well advanced in its next stage.

DIFFERENTIATION OF H. LINEATUM AND H. BOVIS IN THE FIFTH INSTAR

In the first, second, fourth, and fifth instars the larvæ of both species bear a heavy, spiny armature in transverse rows, either broken or continuous, across their body segments. Brauer found that by the presence or absence of armature on a certain posterior segment he could definitely identify the larvæ of the fifth instar, heretofore called the fourth stage, by this character alone. In studying hundreds of specimens of both

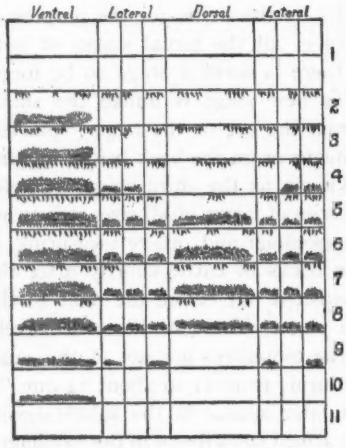

FIG. 1.—*Hypoderma lineatum:* Arrangement of spines on the segments of a fifth-stage larva with a light coat of armature.

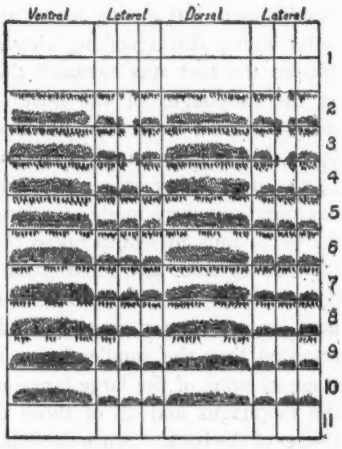

FIG. 2.—*Hypoderma lineatum:* Arrangement of spines on the segments of a fifth-stage larva with a heavy coat of armature.

species the writer found that this character always holds true and is therefore a good one.

The arrangement and variation in the distribution of the spiny armature in fifth-instar larvæ is clearly shown in figures 1 to 4 and Tables I and II. Figures 1 and 2 and figures 3 and 4 represent, respectively, the heavy and light armature of *H. lineatum* and *H. bovis*. The variations presented in Tables I and II are based upon a detailed study of the armature on 106 larvæ of *H. lineatum* and 108 *H. bovis*.

In the tables and diagrams Brauer (*1*) is followed in considering the first segments as cephalic and marked 1, as these segments are so closely fused and the sutures dividing them are often so indistinct that they appear as one. This method of diagraming the spines is a device adopted by Brauer to indicate the difference in spine distribution in the different

species. The wide spaces of the diagrams represent the ventral surface (on the left) and the dorsal surface (on the right) and the narrow spaces the three rows or lateral divisions. The present diagrams were enlarged by the addition of the three narrow spaces on the right in order to show both lateral surfaces and indicate the variations of the spiny armature so often found on the lateral divisions of the same specimen. The spines on the anterior and posterior borders are represented in size and approximate number as they appeared on the specimens selected for study. On the anterior border the heavier spines curve backward, and on the posterior border the numerous smaller spines curve forward.

By referring to the tables it will be seen that the variations in distribution of spines are more marked on the posterior borders of the seg-

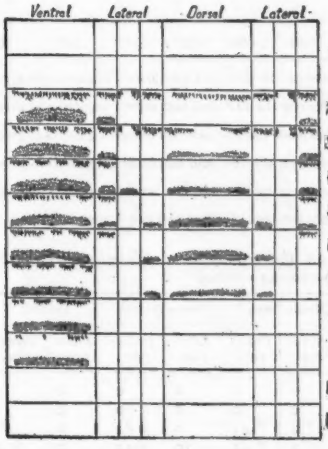

FIG. 3.—*Hypoderma bovis:* Arrangement of spines on the segments of a fifth-stage larva with a light coat of armature.

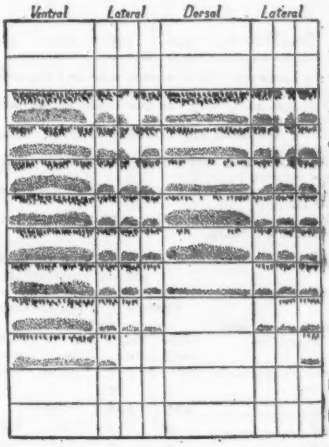

FIG. 4.—*Hypoderma bovis:* Arrangement of spines on the segments of a fifth-stage larva with a heavy coat of armature.

ments except on the ventral surface. On this surface the occurrence of spines is almost constant—that is, all segments from 2 to 10 are armed on their posterior borders in *H. lineatum* and all segments from 2 to 9 are so provided in *H. bovis*. The spines occur on the anterior borders of segments 2 to 9 in both species, only one exception being noted in *H. lineatum*, in which segment 9 was unarmed on this border, and in *H. bovis* one instance in which segment 10 was armed anteriorly, in addition to segments 2 to 9, inclusive. On the lateral divisions of the segments and on the dorsal surface the variation in occurrence of spines is much more marked. It is not uncommon to find certain segments unarmed dorsally while on either side spines are found. The number of larvæ showing such variations is indicated by letters in the figure columns which refer to footnotes.

TABLE I.—*Distribution of spiny armature on the segments of fifth-stage H. lineatum larvæ, based on 106 specimens studied*

Armature on segments No.	Ventral.		Ventro-lateral.		Medio-lateral.		Dorso-lateral.		Dorsal.	
	Anterior.	Posterior.	Anterior.	Posterior.	Anterior.	Posterior.	Anterior.	Posterior.	Anterior.	Posterior.
2 to 10	0	106	0	[a] 19	0	1	0	[a] 32	0	[c] 13
2 to 9	105	0	34	1	0	0	0	[a] 6	[a] 2	[a] 9
2 to 8	1	0	64	0	[a] 20	0	79	0	[f] 88	0
2 to 7	0	0	8	0	29	0	22	0	[d] 16	0
2 to 6	0	0	0	0	48	0	5	0	0	0
2 to 5	0	0	0	0	9	0	0	0	0	0
3 to 9	0	0	0	6	0	[a] 18	0	[c] 11	0	[a] 10
4 to 9	0	0	0	[a] 7	0	[a] 18	0	4	0	4
5 to 9	0	0	0	0	0	2	0	4	0	15
3 to 10	0	0	0	[b] 47	0	[b] 28	0	[c] 41	0	16
4 to 10	0	0	0	[e] 26	0	[d] 34	0	5	0	27
5 to 10	0	0	0	0	0	[a] 3	0	3	0	10
4 to 8	0	0	0	0	0	[a] 2	0	0	0	[a] 2
Total larvæ.	106	106	106	106	106	106	106	106	106	106

[a] One specimen with 1 or more unarmed segments between the first and last armed segments as given in first column.
[b] Two specimens with 1 or more unarmed segments between the first and last armed segments as given in first column.
[c] Three specimens with 1 or more unarmed segments between the first and last armed segments as given in first column.
[d] Four specimens with 1 or more unarmed segments between the first and last armed segments as given in first column.
[e] Ten specimens with 1 or more unarmed segments between the first and last armed segments as given in first column.
[f] Forty-one specimens with 1 or more unarmed segments between the first and last armed segments as given in first column.

TABLE II.—*Distribution of spiny armature on the segments of fifth-stage H. bovis larvæ, based on 108 specimens studied*

Armature on segments No.	Ventral.		Ventro-lateral.		Medio-lateral.		Dorso-lateral.		Dorsal.	
	Anterior.	Posterior.	Anterior.	Posterior.	Anterior.	Posterior.	Anterior.	Posterior.	Anterior.	Posterior.
2 to 10	1	0	0	0	0	0	0	0	0	0
2 to 9	107	108	[b] 29	1	0	0	0	0	0	0
2 to 8	0	0	[d] 65	[a] 89	[a] 2	[d] 43	0	[g] 84	0	82
2 to 7	0	0	11	16	[a] 2	[e] 41	10	[c] 12	0	[a] 18
2 to 6	0	0	3	1	14	1	[a] 18	0	11	0
2 to 5	0	0	0	1	33	[a] 2	[a] 35	0	[f] 27	0
2 to 4	0	0	0	0	55	0	26	0	13	0
2 to 3	0	0	0	0	2	1	18	0	52	0
3 to 7	0	0	0	0	0	[a] 9	0	1	0	2
3 to 8	0	0	0	0	0	[a] 9	1	[c] 6	0	6
4 to 8	0	0	0	0	0	1	0	1	0	0
5 to 7	0	0	0	0	0	0	0	3	0	0
5 to 8	0	0	0	0	0	0	0	1	0	0
2	0	0	0	0	0	0	0	0	5	0
4	0	0	0	0	0	1	0	0	0	0
Total larvæ.	108	108	108	108	108	108	108	108	108	108

[a] One specimen with 1 or more unarmed segments between the first and last armed segments as given in first column.
[b] Two specimens with 1 or more unarmed segments between the first and last armed segments as given in first column.
[c] Three specimens with 1 or more unarmed segments between the first and last armed segments as given in first column.
[d] Six specimens with 1 or more unarmed segments between the first and last armed segments as given in first column.
[e] Seven specimens with 1 or more unarmed segments between the first and last armed segments as given in first column.
[f] Eight specimens with 1 or more unarmed segments between the first and last armed segments as given in first column.
[g] Eighteen specimens with 1 or more unarmed segments between the first and last armed segments as given in first column.

While the presence or absence of spines on the posterior border of the tenth ventral segment is a good distinguishing character of the fifth-stage larva, it is much simpler to distinguish the two species by the shape and structure of the posterior stigmal plates. The flat or level surface of the plate of *H. lineatum* (fig. 5) compared with the distinctly cup-shaped or funnel-form surface of the plate of *H. bovis* (fig. 6) is so well marked that the two species can be identified with the naked eye at sight. If the hair surrounding a warble hole through the skin of an animal is parted and a slight pressure is applied to the skin so as to bring the anal segment of the warble near the surface of the skin it can be viewed through the hole, and a glance is sufficient for determination of the species without extracting it from the host. The size of the stigmal plate of *H. lineatum* is from 0.837 to 1.07 mm. and that of *H. bovis* from 0.971 to 1.27 mm. at its greatest diameter and does not change in size with either species throughout this instar. The structure of the stigmal plates of *H. lineatum* is so formed that the light-colored space between the inward-curving borders around the tracheal opening of the

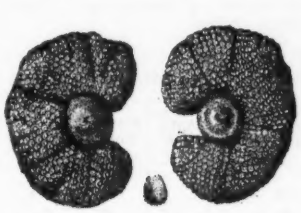

FIG. 5.—*Hypoderma lineatum:* Posterior stigmal plates of fifth-stage larva. Greatly enlarged.

FIG. 6.—*Hypoderma bovis:* Posterior stigmal plates of fifth-stage larva. Greatly enlarged.

respiratory area is usually more than twice as great as the corresponding area in *H. bovis*. This difference is especially noticeable in the younger or lighter-colored specimens. As the larva of the fifth stage grows to maturity and darkens from a light or cream color to black the color of the stigmal plate also changes uniformly, and the age of the specimen can thereby be fairly accurately determined while the grub is still in the host. When the larva has just molted to the fifth instar the color of the plate is light orange throughout. As the larva advances in age the border of the plate turns to a dark brown. A little later the entire plate turns dark brown, and finally just prior to emergence the plate darkens to black. In a series of experiments with various larvicides, conducted at Dallas, Tex., the results of which are to be published later, the color changes of the stigmal plate were very useful in determining the age of the larvæ in the host and the effects of the larvicide on specimens of certain ages. With the dark brown or black larva the finer structure of the stigmal plate is no longer discernible with the naked eye, but the flat surface plate of *H. lineatum* and the cup-shaped

plate of *H. bovis* remain constant throughout the fifth larval instar and also are distinct in the puparia.

DIFFERENTIATION OF THE FOURTH INSTAR OF H. BOVIS AND H. LINEATUM

Available literature on the two species of Hypoderma under consideration gives no description of distinct characters for the identification of the fourth (heretofore known as the third) larval stage. Tabulations of the spiny armature of many fourth-stage larvæ of *H. lineatum* (Table III) and of *H. bovis* (Table IV) revealed that there was no constant character of the armature in either species. The ventral posterior border of segment 10, which is always covered with spines in the fifth larval stage of *H. lineatum* and always naked in *H. bovis*, is nearly always naked in the fourth instar of both species. The armature on the dorsal surface and on the lateral divisions, as given in Tables III and IV, shows that it varies with different specimens of either species as greatly here as it does in the fifth larval stage.

TABLE III.—*Distribution of spiny armature on the segments of fourth-stage H. lineatum larvæ based on 114 specimens studied*

Armature on segments No.	Ventral.		Ventro-lateral.		Medio-lateral.		Dorso-lateral.		Dorsal.	
	Anterior.	Posterior.	Anterior.	Posterior.	Anterior.	Posterior.	Anterior.	Posterior.	Anterior.	Posterior.
2 to 10	1	3	0	0	0	0	0	0	0	0
2 to 9	94	110	0	0	0	0	0	0	0	0
2 to 8	19	1	0	1	0	0	0	[a]1	0	0
2 to 7	0	0	[b]3	1	0	0	0	0	0	0
2 to 6	0	0	[c]37	7	0	0	0	0	0	0
2 to 5	0	0	41	52	0	0	2	0	0	0
2 to 4	0	0	28	8	39	0	55	1	0	0
2 to 3	0	0	5	2	72	0	54	18	2	0
3 to 4	0	0	0	3	0	1	0	1	0	0
3 to 5	0	0	0	22	0	1	0	0	0	0
4 to 5	0	0	0	5	0	1	0	0	0	0
6 to 7	0	0	0	0	0	0	0	0	0	1
2	0	0	0	1	3	3	3	35	69	0
3	0	0	0	4	0	5	0	0	0	0
4	0	0	0	4	0	1	0	0	0	1
5	0	0	0	2	0	0	0	0	0	0
Spineless	0	0	0	0	0	102	0	58	43	112
Total larvæ	114	114	114	114	114	114	114	114	114	114

[a] Segments 4 to 6 unarmed.
[b] One specimen with segment five unarmed.
[c] Three specimens with segment five unarmed.

In studying the characters of the stigmal plate of fourth-stage larvæ collected at Dallas, Tex., and elsewhere in the southern States where only *H. lineatum* exists, and comparing them with specimens collected in the northeastern States where both species are found, it was soon

observed that there was a vast difference in these organs of part of the eastern specimens, and that the others out of the same lots were identical with *H. lineatum* collected locally. Several thousand specimens of fourth- and fifth-stage larvæ collected in all parts of the United States during the past four or five years were all carefully examined, and the fourth-stage larvæ that showed stigmal plates differing from *H. lineatum* were recorded. When these records were then compared with those of the fifth-stage larvæ it was found that all fourth-stage specimens designated as *H. bovis* were from localities where *H. bovis* is present and out of lots that usually contained fifth-stage *H. bovis* larvæ.

TABLE IV. *Distribution of spiny armature on the segments of fourth-stage H. bovis larvæ based on 29 specimens studied*

Spines on segments No.	Ventral.		Ventro-lateral.		Medio-lateral.		Dorso-lateral.		Dorsal.	
	Anterior.	Posterior.	Anterior.	Posterior.	Anterior.	Posterior.	Anterior.	Posterior.	Anterior.	Posterior.
2 to 9	29	29	0	0	0	0	0	0	0	0
2 to 8	0	0	0	0	0	0	0	0	0	0
2 to 7	0	0	0	0	0	0	0	0	0	0
2 to 6	0	0	16	9	0	0	0	0	0	0
2 to 5	0	0	13	19	0	0	0	0	0	0
2 to 4	0	0	0	1	12	[a]1	12	0	0	0
2 to 3	0	0	0	0	17	4	17	5	8	0
2	0	0	0	0	0	15	0	24	18	1
3	0	0	0	0	0	1	0	0	0	0
Spineless	0	0	0	0	0	8	0	3	3	28
Total larvæ	29	29	29	29	29	29	29	29	29	29

[a] Segment three unarmed.

The characters of the stigmal plates in the fourth-stage larvæ can not be seen or the species distinguished with the naked eye as they can be in the fifth stage, but with the aid of a low or medium power microscope they are distinct. If the specimen is placed under the microscope in a vertical position with the posterior stigmal plates upward and so arranged that they can be viewed at right angles to the surface, the structure is visible. *H. lineatum* (fig. 7) presents a group composed of about 20 ring-like or disk-shaped structures constituting the respiratory areas. These disks, as they may be designated, appear in a group forming a circle or almost any other shape. The color of the disks, which of course is the color of the entire plate, is yellowish or yellowish brown. Most of the individual disks are loosely connected by their borders or are often separated either singly or in small groups,

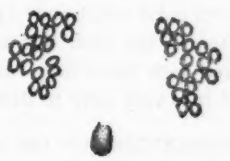

FIG. 7.—*Hypoderma lineatum*: Posterior stigmal plates of fourth-stage larva. Greatly enlarged.

but they are always individually clear and distinct in outline. The color of the stigmal plates remains almost constant during this instar.

While the number of disks is usually close to 20 in each plate it runs as high as 28 or even higher in exceptional cases and as low as 14 in rare instances. The yellowish color and the more distinct separation of the disks readily facilitate counting these structures. The surface of the plates is usually flat in perfect specimens and measures from 0.201 to 0.301 mm. at its greatest diameter.

The characters of the stigmal plate of the fourth-stage larva of *H. bovis* (fig. 8) differ from those of *H. lineatum* (fig. 7) in that the whole plate presents a somewhat larger area which is black and usually contains about 30 disks. The borders of the disks are wider and are all or nearly all heavily fused together so as to present a solid black mass. The number of disks in each plate is also variable, dropping as low as 26 or going as high as 38 in different specimens. The surface of the plate of a perfect specimen is usually convex and projecting slightly above the surrounding tissue. The size of the plate varies from 0.201 to 0.368 mm. at its greatest diameter. With uncleared plates the size of the disks appears to be smaller in *H. bovis* than in *H. lineatum* and they are more indistinct, but after clearing they measure practically the same. The color of the plate remains constant throughout this stage.

FIG. 8.—*Hypoderma bovis:* Posterior stigmal plates of fourth-stage larva. Greatly enlarged.

Discoloration or dryness of specimens sometimes renders determination rather difficult, but if the surface of the stigmal plate in such instances is kept covered with a film of water or alcohol the characters are usually brought out plainly. Occasionally specimens of *H. lineatum* of the fourth instar are found that show stigmal plates of an almost dark brown color which may at first appear rather confusing, but even in such instances the clear and unfused outline of the individual disks if compared with the solidly fused mass of disks of *H. bovis* remains constant, and it is very easy to determine the species by this character alone.

DIFFERENTIATION OF H. BOVIS AND H. LINEATUM IN THE THIRD INSTAR

The third-stage larva, or the first stage found in the back and heretofore known as the second stage, presents no distinguishing characters in either the structure or the shape of the posterior spiracles or in the scanty, minute armature just below the mouthparts and on the end of the anal segment. The spiny armature is entirely lacking on all the middle segments, and that which appears around the posterior spiracles and

below the mouth is so variable in different specimens that it can not safely be relied upon for separating the species in this stage. If the specimen in question, however, is cleared and mounted and the cephalopharyngeal skeleton and mouth hooks, which can rarely be seen in uncleared specimens, are examined under a medium high power of the microscope, the difference in the structure of the mouth hooks can readily be seen and serves to distinguish the species.

In *H. bovis* (fig. 9–12) the upper or foremost ends of the somewhat shortened semicircular or crescent-shaped mouth hooks (fig. 11, B) are distinctly forked near the tip, and the lower or rear ends of the hooks (fig. 11, C) are blunt. In the illustrations (fig. 11, 15, 22) the mouth hooks are flattened out almost horizontally instead of being in a nearly vertical plane as they are in the normal larva. The articulation of the mouth hooks with the cephalopharyngeal skeleton is in the case of *H. bovis* on the end of a slightly projecting knob of the skeleton turning almost at right angles to the axis, while in *H. lineatum* it occurs on the anterior tip of the skeleton. Between the mouth hooks is a sharp spine (fig. 11; 15; 22, A) directed forward and slightly longer than the foremost tips of the forked mouth hooks. This spine is evidently used to assist in piercing or boring through the tissue while the larva wanders toward the back of the host. After the larva reaches the back and molts to the fourth stage the skeleton with the mouth hooks and spine is cast off.

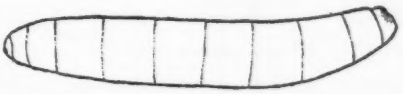

FIG. 9.—*Hypoderma bovis:* Lateral view of third-stage larva. × 4.

The structure of the mouth hooks of the third-stage larva of *H. lineatum* (fig. 13–16) is more regularly crescent-shaped, is slightly more extended from end to end (fig. 15, B, D), but is otherwise similar in general outline to *H. bovis* with the exception of being distinctly pointed instead of forked like *H. bovis* at the anterior end (fig. 15, B) and having a strong pointed and backward-curving tooth (fig. 15, C) projecting outward about one-third of the length of the entire hook from the anterior tip. The lower or rear end (fig. 15, D) of the mouth hook of *H. lineatum* is also slightly pointed, not as much so as the forward end but considerably more than the rear or backward end of that of *H. bovis*. Out of a considerable number of larvæ of this stage extracted from the back after the hide of the host had been punctured only a few specimens were found that showed a few very minute spines, barely visible under a high power of the microscope, along the anterior borders of the first few segments. If a larva of this stage is placed under the microscope in a vertical

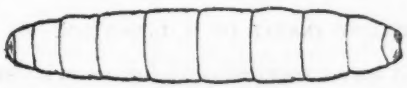

FIG. 10.—*Hypoderma bovis:* Ventral view of third-stage larva. × 4.

position with the anterior end upward and so arranged that the anterior spiracles appear in the center of the field and the mouthparts near the edge, one can see a single, small, but distinct, horn-like appendage at a distance about equal to that of the mouthparts and in a direction from the spiracles opposite from the mouthparts. There are no spines around the base of this appendage, which is smaller and more indistinct in this

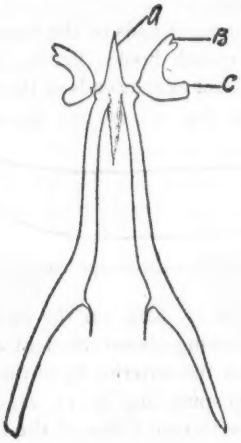

FIG. 11.—*Hypoderma bovis:* Cephalopharyngeal skeleton and mouth hooks of third-stage larva. *A*, spine; *B*, anterior end, and *C*, posterior end, of mouth hooks. × 125.

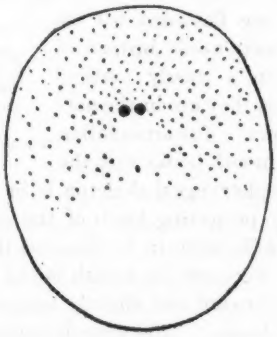

FIG. 12.—*Hypoderma bovis:* Posterior spiracles and spiny armature on posterior half of caudal segment of third-stage larva. Greatly enlarged.

larval stage than in the two younger stages and is entirely absent or invisible in the two larger stages.

DESCRIPTION OF THE SECOND INSTAR OF H. LINEATUM

The second-stage larva has not been recognized heretofore as an instar distinct from that later found in the esophagus and in the back, hence it will be rather fully described. The smaller larvæ found in the gullet are in this stage. Specimens ranging from slightly less than 3 mm. in length and upward have been collected from esophagi of slaughtered cattle at Fort Worth (Tex.) packing houses as early as April 1. During May, 1920, a considerable number of larvæ, all of this stage, measuring from 3 to 6 mm., were taken by E. E. Wehr from esophagi of locally raised cattle slaughtered at a Dallas packing house. These examinations were continued by the writer at weekly intervals. All the larvæ (nearly 400) examined up to August 15, 1920, were found to be still in the second stage. These ranged up to 9 mm. in length. In the general collection made by the writer many other specimens ranging up to as high as 14 mm. in length also prove to be of this stage. All larvæ in this second instar

were taken from the esophagi and were collected in various localities, mostly in the southern States. An effort was made to obtain this stage of both species, but so far the writer's collections of small larvæ in regions where *H. bovis* is found apparently were made too early, and only specimens of *H. lineatum* were obtained. Although a similar stage of *H. bovis* has not been observed so far, it seems reasonably safe to assume that it is also present, since the general characters of the four known larval stages agree in all respects with those of the first, third, fourth, and fifth stages of *H. lineatum*. The comparisons of the larvæ of each stage for the two species under consideration have been based on the assumption that there are five stages of *H. bovis*.

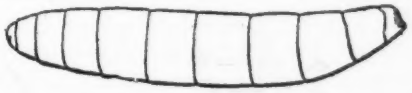

FIG. 13.—*Hypoderma lineatum:* Lateral view of third-stage larva. × 4.

The distinguishing character of this stage lies in the armature which is present on every segment of the entire larva (fig. 17–19). In form, this stage is very similar to the third-stage larva at the time it reaches the back, but of course it is much smaller and not so distinctly segmented. When the armature alone is considered one is led to believe at first sight that it is the first-stage larva which hatches from the egg. After closer examination and comparison with the armature of the first stage, however, it can easily be observed that this is an entirely different coat of armature. The spines not only differ by being smaller in size but also, on the terminal segment at least, differ vastly in structure. While the armature on the middle segments is not as plain as in the first, fourth, and fifth stages, it is nevertheless easily seen with a low power of the microscope and appears in transverse rows very regularly placed on at least the anterior part of each segment. On the second to fourth segments, inclusive, the spines in the anterior row are rather densely placed and are the largest in size. Following the first row are several more irregularly placed rows, in which the spines decrease in size and abundance toward the posterior border of the segment. On the fifth, sixth, and seventh segments the anterior row is also quite regular, but the spines are smaller and farther apart than in the same rows of the preceding segments. The spines behind the anterior row on these middle segments also decrease in number and size in the same proportion as on the anterior segments. On the eighth and ninth segments there is a further decrease in size and number of spines, and the posterior half of the segments is almost naked, except laterally, where small spines extend farther back. The anterior part of the tenth segment is covered ventrally with a band of spines

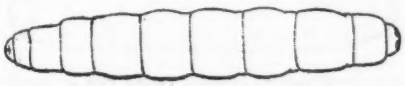

FIG. 14.—*Hypoderma lineatum:* Ventral view of third-stage larva. × 4.

consisting of at least five rows, in all of which the spines are slightly larger and more uniform in size throughout than on the preceding segments. Laterally this band of spines narrows down to the first two or three rows which extend on around over the dorsal side. The eleventh or caudal segment is armed with spines of three distinct types. Along the anterior border are a few small spines similar in structure to those along the anterior border of all the preceding segments. Closely following these, except for a narrow space ventrally, are numerous stout spines consisting of a large, circular, blackish, slightly elevated base, in the interior of which arises a short, stout spine less in length than the diameter

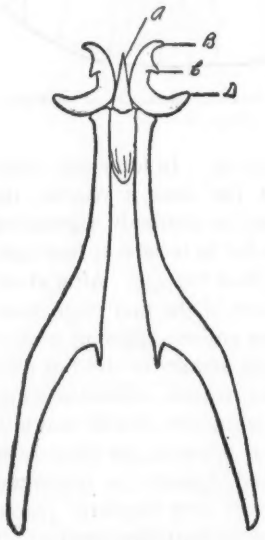

FIG. 15.—*Hypoderma lineatum:* Cephalopharyngeal skeleton and mouth hooks of third-stage larva. *A* spine; *B*, anterior end, and *D*, posterior end, of mouth hooks; *C*, tooth. Greatly enlarged.

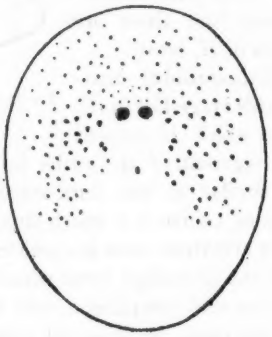

FIG. 16.—*Hypoderma lineatum:* Posterior spiracles and spiny armature on posterior half of caudal segment of third-stage larva. Greatly enlarged.

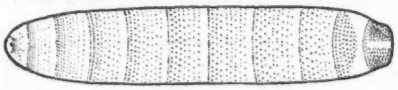

FIG. 17.—*Hypoderma lineatum:* Ventral view of second-stage larva. × 13.

of the base. Surrounded by these spines are the posterior spiracles, which are represented by circular spots or disks with two or three very flattened and triangular-shaped spines on the border of each. These flattened spines are hardly visible in the third-stage larva even under high magnification and disappear entirely with the fourth and fifth stages. The fused anterior terminal segments bearing the anterior spiracles, centrally located from an anterior view, and with the mouth hooks ventrally and the small horn-like appendage dorsally located, are thickly covered with a band of spines below the mouthparts, extending on around and beyond the spiracles laterally in a decreasing number toward the dorsum, where

this band broadens out again and envelops the horn-like appendage. The base of this appendage is surrounded by a dense group of small spines. The posterior border of these segments is covered with small spines, decreasing in number and size toward the border.

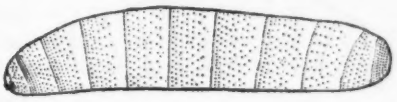

FIG. 18.—*Hypoderma lineatum:* Lateral view of second-stage larva. × 13.

Aside from the greater size of the third-stage larvæ after reaching the back, the second stage may be easily distinguished by the distribution of armature. In the third stage the spines on the cephalic segment are fewer and are clustered beneath the mouthparts and not scattered as in the second instar. In the third stage the armature is absent from all the following segments except the caudal. The few spines that are left below the mouthparts of the third stage and the flattened spines on the border of the posterior spiracles are actually smaller and more indistinct than they are in the second stage, while the numerous spines with enlarged bases surrounding the posterior spiracles of the third stage are considerably larger than those in the second stage.

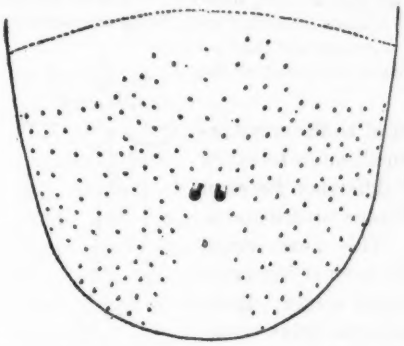

FIG. 19.—*Hypoderma lineatum:* Posterior spiracles and spiny armature on caudal segment of second-stage larva. × 100.

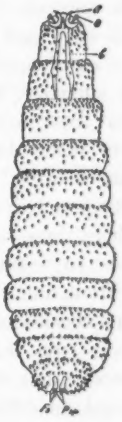

FIG. 20.—*Hypoderma lineatum:* Ventral view of first-stage larva. *A*, Mouth hook; *B*, anterior spiracles; *C*, cephalopharyngeal skeleton; *Fs*, flattened spines on border of posterior spiracles; *P sp.*, posterior spiracles. × 121.

Riley (9), in his description of the second-stage larva, states that the larvæ in the esophagus measure from 11 to 14 mm. and are spineless except for a cluster above the mouthparts and the posterior half of the caudal segment. This description agrees in practically all respects with the third-stage larva of both species and is undoubtedly that of a third-stage larva taken from the esophagus. It is certain that Riley would not have overlooked the spiny armature of the larvæ of the earlier stage if any of them had been studied. This may be further substantiated by the fact that the writer has obtained as many as 20 specimens, ranging from 11.7 to 14.6 mm. in length in one lot taken from the esophagus, that were all in the third stage.

Koch (7), a veterinarian of Denmark, briefly mentions the fact that he observed spines on the very small larvæ which he found in the esophagus and states that this is the first-stage larva. He further claims that the first-stage larva molts for the first time after it has reached the back and has punctured the hide. His reasons for this statement are that—

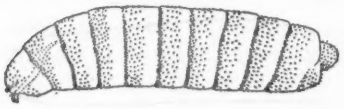

FIG. 21.—*Hypoderma lineatum:* Lateral view of first-stage larva. Caudal segment halfway telescoped. Approximately × 116.

While the larva is in the early part of this stage (first stage) it is clear as glass and transparent, but later it becomes yellowish white, and while the armature of spines is easily observable in the young larva they are less noticeable in the older larva, partly because these are more opaque and partly because the dark color of the spines gradually is lost; and finally it may be stated as a third reason that the spines are not only comparatively but actually smaller in the older larva. It seems as if they become somewhat worn during the migration through the body of the cattle, but it is certain that they remain present and in the same arrangement on the body of the larva throughout this entire period.

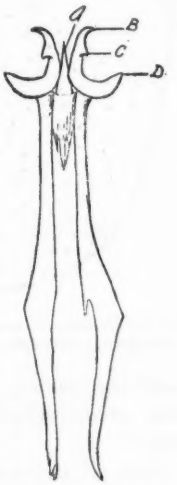

FIG. 22.—*Hypoderma lineatum:* Cephalopharyngeal skeleton with spine and mouth hooks of first-stage larva. *A*, spine; *B*, anterior, and *D*, posterior, end of mouth hooks; *C*, tooth. Greatly enlarged.

Attention has already been called to the spiny armature of the second stage or small larva found in the esophagus as the principal difference between this stage and the larger or third-stage larva found in the esophagus and in the back. This alone should be sufficient to convince even the most severe critic that these are larvæ of two distinct stages. However, it may be stated further that if the spiny armature became "worn," as Koch stated, it would nevertheless leave at least a scar or mark in the skin where these spines had been located; but there are none to be found, not even under very high magnification, and it seems impossible that the spines could have been cast off without also casting off the skin. It is true that there is quite a difference in the amount and the arrangement of the spiny armature found on different specimens of the smaller larvæ taken from the esophagus, but this difference is not more marked or unusual than that which is encountered in different specimens of either the fourth or fifth stages, and as a whole the change in character and arrangement of the armature from the fourth to the fifth stage is not as marked as the change found between the second-stage larva in the esophagus and the almost spineless third-stage larva taken from the esophagus or from the back..

DISTINGUISHING CHARACTERS IN FIRST-INSTAR LARVÆ OF H. BOVIS AND H. LINEATUM

Riley (*9*) described the first-stage larva of *H. lineatum* (fig. 20–23) which he obtained from the egg just before hatching and which does not differ in any way from the larva normally hatched from the egg. Careful examinations of some of the hundreds of larvæ of this species hatched from eggs in an electric incubator at the Dallas laboratory agree well with Riley's description; Riley, however, does not mention the anterior horn-like appendage, which is large and very distinct in this stage. The armature on all the segments except the posterior part of the first stage is very dense and considerably larger than on the second stage. On the caudal segment of the first stage the spines with an enlarged circular base are not present, although this segment is well covered with spines similar to but larger than those on the preceding body segments. The flattened spines (fig. 20; 23, Fs) on the border of the posterior spiracles are more than twice as large as the surrounding spines. The dense large spines on the body segments and large flattened spines on the margins of the posterior spiracles of the first-stage larva are in striking contrast with the smaller and much thinner armature on the body segments and small flattened spines on the border of the posterior spiracles surrounded by larger spines with the heavy blackish base in the second stage.

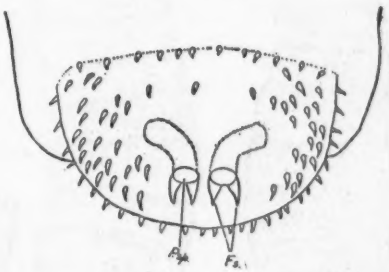

FIG. 23.—*Hypoderma lineatum:* Posterior spiracles and spiny armature on caudal segment of first-stage larva. *P sp.*, posterior spiracles; *Fs.*, flattened spines on border of spiracles. × 500.

The first-stage larva of *H. bovis* (fig. 24) was first described by Carpenter, Hewitt, and Reddin (*2*). The spiny armature on the cephalic and all the body segments is very similar to that of *H. lineatum*, but the arrangement of the spines on the caudal segment differs somewhat, and the spines are considerably larger in *H. bovis*. The flattened spines, usually three in number, on the border of the anal spiracles of *H. bovis* appear smaller in comparison with the large surrounding spines and are actually smaller than in *H. lineatum*. The peculiar type of spines with large circular bases as found in the second and third stages of *H. lineatum* and third stage of *H. bovis* is here absent as it is in *H. lineatum* of the same stage. While the armature of the first-stage larva of the two species in question may differ somewhat, it is hardly reliable for the differentiating of the two species. The characters of the mouth hooks, however, which are here plainly visible in the uncleared specimens with the aid of a

medium power of the microscope, are very reliable and serve to differentiate the species readily. The forked anterior end and the blunt rear end of the mouth hook of *H. bovis* are so distinctly different from the sharply pointed anterior end with a well-formed tooth some distance below and the slightly pointed rear end of the hook of *H. lineatum* that the two species can be separated almost at sight in the first instar.

The mouth hooks of the first, second, and third stages do not change in structure with specimens of the same species except that they become slightly heavier, somewhat shorter, and stouter in the second and third

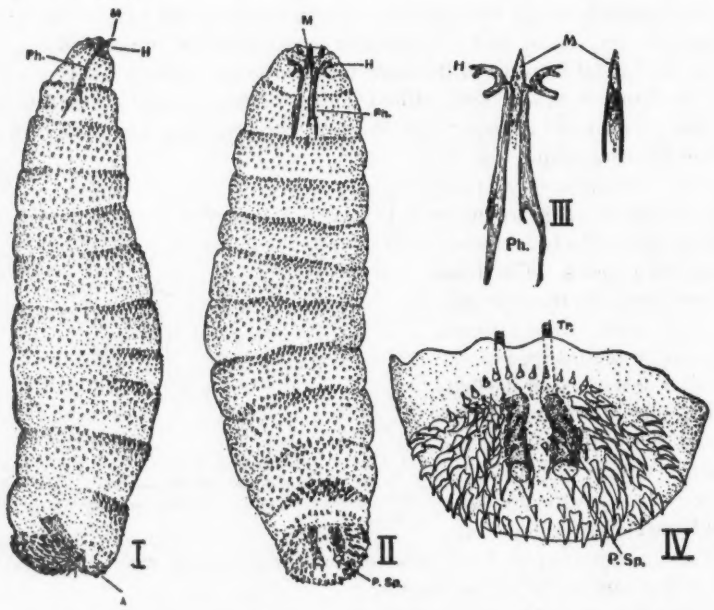

FIG. 24.—*Hypoderma bovis:* First-stage larva. I, Lateral view; II, ventral view; III, cephalopharyngeal skeleton with spine and mouth hooks; IV, caudal segment. *Ph*, Skeleton of pharynx; *H*, mouth hooks; *M*, spine; *Tr*, air tubes; *P sp.*, posterior spiracles. (Carpenter and Hewitt.)

stage, but the two almost parallel rods or arms of the cephalopharyngeal skeleton of the first-stage larva spread considerably posteriorly and become heavier in the second and especially in the third stage.

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PATHOGENICITY OF CORTICIUM VAGUM ON THE POTATO AS AFFECTED BY SOIL TEMPERATURE[1]

By B. L. RICHARDS

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INTRODUCTION

In a paper now in press (*12*)[2] the author treated in detail the question of the pathogenicity of *Corticium vagum* B. and C. (*Rhizoctonia solani* Kühn) and its effects upon the potato plant. Experimental data were presented which showed definitely that under certain conditions the fungus in question becomes an aggressive parasite upon this host. Attention was called, however, to a number of puzzling variations exhibited by this pathogen in its power to attack and produce characteristic lesions on the potato stem. It is frequently noted in the field, for example, that whereas in certain cases the "Rhizoctonia" or the sterile stage of *C. vagum* apparently acts as a definite cankering parasite on potato stems, in other cases where the fungus is present in abundance little or no damage results. The mycelium, in fact, may grow and closely envelop the basal portions of the potato stem as a superificial web with no indication of a lesion or canker. The problem is further complicated by the fact that in certain districts canker-free stems and particularly clean tubers, showing no sings of "scurf," are harvested uniformly from sclerotia-covered seed. Such facts, together with the serious lack of experimental evidence supporting the pathogenicity of the fungus on the potato have led many critical observers to question whether "Rhizoctonia" is of primary or of only secondary importance in the production of the stem cankers so generally attributed to it.

Recent observations in Utah and in Wisconsin have led the workers of these two States to a firm belief that the parasitism of *Corticium vagum* is dependent to a large extent upon soil and climatic conditions. The relative importance, however, of the various factors responsible for the puzzling variation in the pathogenic action of the fungus in question is by no means clear. It has become evident, as previously pointed out (*12*), that further progress on the "Rhizoctonia problem" is dependent upon a better understanding of the biology of the fungus and of the various factors that influence or control its parasitic activity.

[1] The results here reported are based upon greenhouse investigations made during 1917, 1918, and 1919, at the Department of Plant Pathology of the University of Wisconsin. During the seasons of 1918 and 1919, soil temperature studies were made with the potato under natural field conditions. These studies, together with greenhouse experiments on the pea and bean, paralleling those on the potato, will furnish the basis for later reports. The writer wishes to express his indebtedness to Prof. L. R. Jones for helpful suggestions and criticisms during the progress of the work.

[2] Reference is made by number (italic) to "Literature cited," p. 481-482.

A recognition of this fact, together with the opportunity offered at the Department of Plant Pathology of the University of Wisconsin, led the writer to conduct a series of studies upon soil temperature in its various relations as affecting the pathogenicity of *Corticium vagum* upon the potato and other hosts. The purpose of this paper is to report part of the results of these investigations.

One of the most important features of the recent development in phytopathology, as pointed out by Jones (*6*), has been the directing of the attention of workers in this field to the vital relation of the temperature of the soil to a large number of our most serious soil diseases. Our present knowledge on this subject is at best limited and fragmentary, and the degree to which soil temperature becomes a rigid controlling factor in determining pathogenicity is known for but a small number of soil pathogens. These data do not permit of extensive generalization. It is evident that *Corticium vagum*, with its wide range of hosts, offers an especially favorable object for the study of parasitism in relation to the temperature of the soil.

REVIEW OF LITERATURE

Observations on soil temperature in relation to the pathogenicity of *Corticium vagum* on its various hosts are few and conflicting. Rolfs (*13*, *14*) concludes that—

> a high temperature and plenty of moisture are necessary for the rapid development of the fungus—

and correlates the high death rate of potato plants in Colorado with excessive irrigation during periods of hot weather.

Peltier (*11*, *p. 283-285*), in his greenhouse experiments with the carnation and other hosts, obtained a higher degree of infection with the fungus during the months of June and July and September and October than during the cooler months of spring and winter. He supplies other minor data to support this relationship and finally concludes his observations as follows:

> A high temperature, 88° F., together with either too little or too much moisture, determines to a large degree the virulence of the strains.

It is evident that this writer has reference here to air temperatures and, therefore, adds but little to our knowledge of the exact soil temperatures conducive to the pathogenicity of the various strains of the fungus. In his later statement we are again left in doubt as to whether he has in mind only one or the many hosts with which he worked.

Morse and Shapovolov (*8*) noted that in a certain potato field held under their observation 50 per cent of the plants showed lesions in the middle of July, while on August 4, 91 per cent showed evidence of attack by the fungus. No temperature data were presented, and it is not clear that temperature was an important factor in this relationship, since length of

exposure, soil moisture, and the growth of the new tissues, together with other possible factors, might easily have accounted for this observed difference.

Balls (*1*), on the other hand, presents data from critical field observations which indicate definitely that cool temperatures favor the pathogenic action of the fungus *Rhizoctonia solani* on cotton. The data presented also suggest that the cool weather increases the severity of attack both by retarding the growth of the young cotton seedlings and by favoring definitely the action of the fungus upon the plant tissues. At the higher soil temperatures it appears the plant may escape unharmed even in a heavily infested field. This writer states his conclusions as follows:

> There is no doubt, in view of this year's experience, that given a supply of healthy mycelium in the soil of average texture, the amount of damage done to the cotton crops depends upon the temperature of the soil.

By pure culture work Balls (*2*) was further able to show that "Rhizoctonia" could attack the cotton plant vigorously at 22° C., but he obtained no infection at 33° C.

GENERAL CONSIDERATION OF THE FACTORS INVOLVED

Progress in the analysis of so complex and fluctuating a condition as is found in parasitism can be made best by the common procedure of varying one factor in the environment while holding all others under control. Because of the complex nature and the interrelation of the factors involved, an absolute control of the possible variable is rendered difficult if not impossible. Proper evaluation must be given those variations outside the limits of control. The problem, however, becomes further complicated in that the variables concerned must be controlled as nearly as possible, at a range approximately optimum for the parasitic relation under consideration. Wholly safe conclusions as to the importance of any one factor are possible, therefore, only when the value of several of the most important relations contributing to a parasitic state have become known.

Such factors as are concerned in influencing the parasitic action of *Corticium vagum* on the potato might be considered as both hereditary and environmental in nature. Of the former group, strain differences of the fungus and host susceptibility are of first importance. The controlling features in the environment, however, are more numerous and may be listed for convenience as follows: (1) the oxygen supply of the soil, (2) the soil temperature, (3) the soil moisture, (4) the acid or alkaline reaction of the soil, (5) the organic matter in the soil, (6) the soil texture, and (7) the soil flora and fauna, including the degree of soil infestation of the strains of the parasite under investigation. At present, the true relation and importance of any one of these various factors to the parasitic

state existing between *C. vagum* and its numerous hosts is not known. In the present soil temperature studies the use of the same soil and a single strain of host plant made the problem of controlling the various influencing factors relatively simple. The methods employed are discussed below. In general, an attempt has been made to depart as little as possible from the natural conditions of potato culture.

GENERAL METHODS AND MATERIAL

APPARATUS

The experiments were conducted in especially constructed water jackets now in use for soil temperature studies in the greenhouses of the Department of Plant Pathology of the University of Wisconsin. The essential features of these were described and illustrated by Jones (*6*) in 1917. Johnson and Hartman (*5*) in 1918 gave further details as to their structure and convenience for temperature control. It should be mentioned here that each unit or tank as used in the experiments consists of an insulated water chamber 3½ feet long, 2 feet wide, and 1½ feet deep. Eight cans 7 inches in diameter and 12 inches deep were so arranged in each water jacket as to form two parallel rows of four cans each. The cans were supported in the water to a depth which just permitted of safety from overflow. The ½ inch to 1 inch of the cans thus remaining above the water projected into the hole in the cover in such a way as to provide for ample lateral support. Cold water and steam pipes with outlets were arranged in connection with the tanks so as to permit of the convenient use of either steam or water. Electric heating units were also placed at the bottom of the water jackets that were kept at the higher temperatures. Each water jacket thus equipped became an independent unit, with a possible eight pots of soil all held at the same temperature for the growth of plants. The range of temperatures within the temperature limits of plant growth, therefore, was limited only by the number of units employed.

TEMPERATURE CONTROL

The large number of tanks rendered the use of automatic temperature regulation impracticable. It was found, however, that by personal adjustments three times during the 24 hours at intervals of approximately 8 hours each, the temperature could be controlled within a range of variation sufficiently narrow to be adequate for obtaining the required data. At each visit the various water temperatures were recorded and proper adjustment was made. At those temperatures which approached the temperature of the greenhouse, the water was adjusted to the exact degree desired for the soil. At the lower and higher extremes, however, it was found necessary to raise or lower the temperature of the water

sufficiently to counterbalance the amount of variation above or below that which was desired.[1]

At the highest temperature the water was maintained at an extreme range of variation of 3°, or from 28.5° to 31.5° C. At 27° this range of variation was less than 1.5°, while at 24° and at those temperatures approaching that of the greenhouse the total temperature variation rarely exceeded 1°. With a mat of wet sphagnum on the cover of the tanks and with high collars around each can, the variations at the lower temperatures of 9° and 12° were held within a range of less than 2°. Under the system of regulation, the extremes of the variations were of relatively short duration.

Owing to the direct exposure to the surrounding atmosphere the surface of the soil in the cans held at the extreme high and low temperatures varied somewhat below and above that of the water in the respective tanks. These differences could not be detected at a soil depth below 2 inches. Since the potato sets were planted at a depth of 5 inches and since no variation in the vertical distribution of stem lesions could be detected, the average mean temperature of the water in each tank was taken as the temperature of the soil[2] at which the plants were grown. The air temperatures in thee greenhouse at which the plants were grown were maintained in general between 17° and 22° C.

SOIL MOISTURE

Determinations made at the beginning of each experiment showed the moisture content to vary in all experiments between 20.4 per cent and 24.8 per cent of the dry weight of the soils used. This range of soil moisture had been previously determined to permit of uniform infection of potato stems, and no further precaution was taken to regulate more definitely the relation of the moisture content in the soils in the various experiments. The maintenance of a constant water relation throughout any one series, however, became a much more complicated process. The large number of cans used in the experiment and the relatively short period of growth of the plants rendered the use of the Livingston auto-irrigators (7) impracticable. The direct weight method was finally adopted. In this method precautions were taken at the beginning of each experiment to obtain a uniform water content of the soil used in any experiment. In the process of planting, all cans were then filled to exactly the same weight, and during the progress of the experiment the

[1] At the higher temperatures, the variation in the temperature of the water in all cases fell below those desired. The reverse was true for those below the temperature of the greenhouse. The adjustments found necessary were as follows:

Desired temperature—30°, 27°, 24°, 21°, 18°, 15°, 12°, 9° C.

Adjusted temperature—31.5°, 28°, 24.5°, 21°, 18°, 15°, 11.5°, 8° C.

[2] The figures recorded in all tables must be considered as the exact calculated average of the soil temperatures at which the crops were grown and should not be assumed to indicate a degree of accuracy in temperature control as might be implied by the retention of the fractions given in the tables.

water relation was kept constant by frequent weighing and addition of water to restore that lost by evaporation from the soil or through transpiration by the plants. The weighings were usually made every two or three days; at the higher temperatures water was added more frequently as required.

SOURCE OF FUNGUS

A single strain [1] (201) of sterile stage of *Corticium vagum* was used in all the experiments in which artificial methods of soil inoculation were employed. The fungus was increased on bean pods and was introduced into the soil usually after about six weeks' growth on this medium. In three experiments the soil was inoculated by sclerotia upon the surface of the tubers used for seed.

SOIL INOCULATION METHODS

The methods of soil inoculation followed were essentially those described for the work on the pathogenicity of the fungus. They need not be discussed here. In general, where artificial methods were employed the inoculum was placed below the potato sets so as to make sure that none of the material introduced would come in contact with the growing stems. The sets in all cases were planted at a depth of 5 inches. After planting, the cans were allowed to remain under uniform condition for a period of six days, at the end of which time the temperatures were adjusted in the various tanks.

In removing the plants at the conclusion of each experiment the soil in each can was first saturated with water for a period of 24 hours. The roots and stems were then washed free from dirt by a gentle stream of water from the hose.

QUANTITATIVE INDEX

Previous field and greenhouse experiments had shown clearly that owing to the peculiar nature of the attack of *Corticium vagum* (*12*) the percentage of the potato stems showing lesions gave no accurate idea of the damage resulting to the plants. The degree of the intensity of injury to the stems was used, therefore, as an index for determining the different temperature values (Pl. 89–93). In an attempt to express this relationship the diseased stems occurring at each of the various temperatures were divided into three categories: Slightly injured, severely injured, and cut off. All stems showing lesions ranging from the first indications of disease to those sufficiently serious to interfere with the physiological processes of the plant were listed as slightly injured. Stems

[1] This strain is the same employed in the previous experiments on pathogenicity, for the record of which the reader is referred to the earlier paper (*12*). The term "strain" is used here with no special morphological or physiological significance. It indicates, rather, the results of a single isolation from a definite locality.

showing lesions which either from depth of penetration or from extent of surface destroyed appeared definitely to interfere with the activity of the plant were classed as severely injured. In the third group were placed all stems showing definite growing-point destruction and also those which had actually been cut off by the operation of the fungus subsequent to the appearance of the stem through the soil. In order to obtain a quantitative expression of the intensity of injury at each temperature, the percentage of plants occurring in each class was determined and units 1, 2, and 3 were allowed for each percentage in the three classes slightly injured, severely injured, and cut off.

EXPERIMENTAL STUDIES

In all the experimental work with the potato, the application of the results to the interpretation of the operation of the fungus under natural field conditions was kept constantly in mind. In order to eliminate all possible interfering organisms and to establish a firm basis for judgment, experiments were first conducted with pure cultures of the fungus in sterile soil. The results obtained under these extremely artificial conditions were finally supplemented by those obtained with the temperature equally well controlled, but with other relationships of the host and the fungus approaching as nearly as possible those found under natural conditions. As a final control the temperature work was carried into the field, where plantings and inoculations were made at definite intervals and the temperatures recorded throughout the growing season. In addition, valuable temperature data were obtained during 1918 and 1919 from the disease-control experiments conducted on a rather extensive scale in important potato-growing districts of northern Wisconsin. These latter field studies as stated will furnish the basis for a later report.

EXPERIMENT 1.—In the first experiment four tanks with eight cans each were used. The water in the individual tanks was held at approximately 16°, 19°, 23°, and 29° C.

The soil used was sterilized with steam for 7 hours at two different periods 24 hours apart and at a temperature of approximately 97° C. Two half tubers of the Irish Cobbler variety, treated previous to cutting, were then planted with the inoculum in each of six of the eight cans in each tank. Two cans in each tank were left for the growth of control plants in uninoculated soil.

Thirty-eight days after planting the plants were removed and examined. The total intensity of stem injury together with the percentage of stems injured is shown in Table I and graphically in figure 1.

The most serious types of lesions occurred unmistakably at the two lower temperatures. Growing-point injury was found only at the lowest temperature of 16° C. The injury on the stems at both 24° and 29° was very slight.

TABLE I.—*Effect of growing Irish Cobbler potatoes at different temperatures in soil inoculated with a pure culture of Corticium vagum*

EXPERIMENT 1

Temperature (° C.).	Number of sets planted in each can.	Number of stems grown in uninoculated soil.	Stems grown in inoculated soil.						
			Total number.	Number slightly injured.	Number severely injured.	Number cut off.	Number uninjured.	Percentage injured.	Intensity of injury (points).
16.....	2	11	33	7	17	2	7	78.7	142.2
19.....	2	9	21	7	5	.....	9	56.6	80.0
23.....	2	12	22	14	.....	.....	8	66.2	66.2
29.....	2	4	16	4	.....	.....	12	25.0	25.0

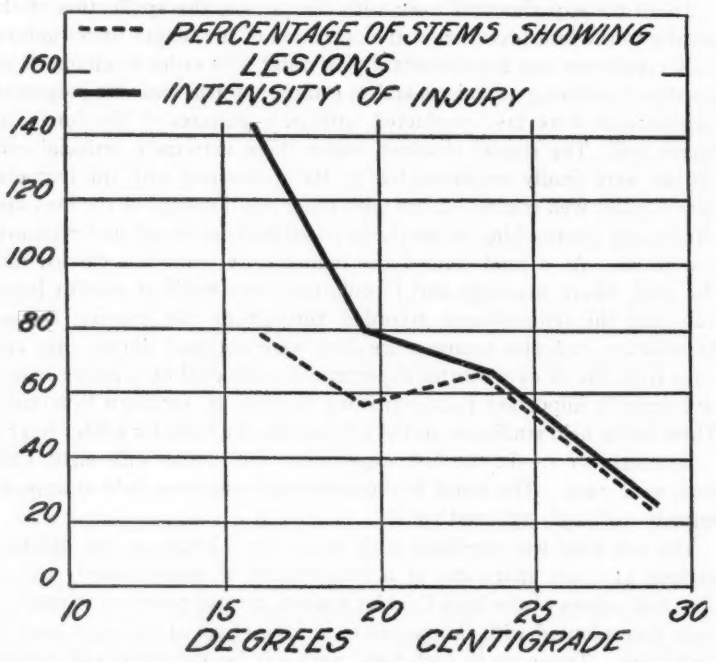

FIG. 1.—Relation of soil temperature to the severity and to the distribution of the injury on potato stem caused by *Corticium vagum* (experiment 1).

All control plants remained entirely free from lesions except those in one can in each of the two tanks held at the two lower temperatures. These plants showed definite brown cankers accompanied by the characteristic mycelium of *Corticium vagum*. The lesions, however, were relatively slight and indicated a possible late infection. The accidental inoculation of the soil in these control pots may have resulted in one of three ways: (1) From imperfect surface sterilization of tubers used for

seed, (2) from the growth of the fungus from the inoculated to the control pots through the moist sphagnum used for insulation, or (3) from the basidiospores from the corticium stage of the fungus which occurred abundantly during a warm period in all the aerial parts of all the inoculated plants. The last explanation appears the most probable.

EXPERIMENT 2.[1]—The results obtained in experiment 1 indicated that the fungus is capable of causing diseases at a temperature much lower than 16° C. It was decided for subsequent experiments to include the possible temperature range at which the potato plant might be grown profitably. This plan resulted in increasing the number of tanks in the series to eight. These were maintained approximately at the following temperatures: 9°, 12°, 15°, 21°, 24°, 27°, and 30°. The 8 tanks containing 8 cans each were placed side by side, making four series of 16 cans, 64 in all. Throughout this and subsequent experiments one series of 2 cans in each tank was used for growing control plants. The other three series were used for growing plants in inoculated soil.

In this experiment two series were run with sterile soil. In a third series unsterilized soil was used. The sterilized and unsterilized soils were represented separately in the two control cans in each tank. Treated southern-grown Irish Cobbler potatoes were used for seed. These had begun to sprout and were in good condition for growth. The results are presented graphically in figure 2.

TABLE II.—*Effect of growing Irish Cobbler potatoes (southern seed) in soil inoculated with Corticium vagum and held at various temperatures*

EXPERIMENT 2

Temperature (° C.).	Number of sets planted.	Number of stems grown in uninoculated soil.	Stems grown in inoculated soil.						
			Total number.	Number slightly injured.	Number severely injured.	Number cut off.	Number uninjured.	Percentage injured.	Intensity of injury (points).
9	1	5	17	.....	5	.....	12	29.7	59.4
11.6	1	4	13	2	.....	.....	11	15.0	15.3
15	1	5	12	2	1	.....	9	24.9	33.2
17.4	1	5	14	1	5	4	4	71.2	153.8
21	1	6	10	1	6	.....	3	70.0	130.0
23.7	1	8	14	.....	3	.....	11	21.4	21.4
26.8	1	5	12	2	1	.....	9	24.9	33.2
30.3	1	6	10	.....	.....	.....	10	.....	.....

At the conclusion of the experiments the plants grown at the temperatures from 15° to 30° C. ranged from 2 to 5 inches high. Those grown in the 12° tank were about 1 inch above the soil line, while but few in the

[1] In an experiment run immediately after experiment 1 and under conditions as outlined in experiment 2 the inoculum, consisting of the fungus on sand-cornmeal mush, was mixed throughout the first 5 inches of soil. The results were so irregular and the root system of the inoculated plants was so unbalanced that the data were discarded. The experiment is not given a number in the series of tests. The control plants of this experiment were used for the measurements given in Table X and were photographed (Pl. 88).

tank held at 9° had succeeded in getting above the surface. The plants were thus removed at a period too early to obtain reliable data as to the effects of the fungus on the shoots above the ground. The results of the observation made 30 days after planting are shown in Table II.

The results were surprising, in that stem lesions occurred throughout the entire range of temperatures from 9° to 27° C. No lesions were found on the stems grown at a soil temperature of 30°. The greatest

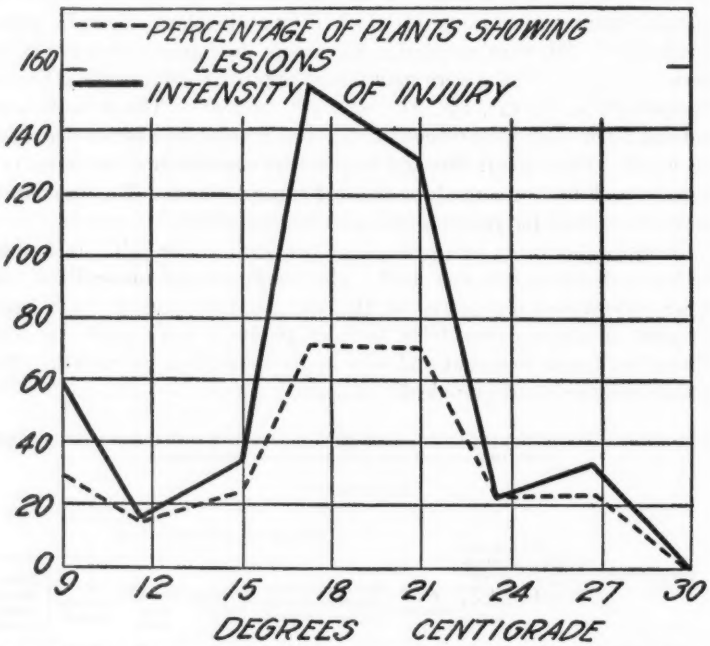

FIG. 2.—Relation of soil temperature to the severity and to the distribution of the injury on the potato stems caused by *Corticium vagum* (experiment 2).

degree of injury occurred unmistakably at 18°. The plants in the soil held at 21° were also severely damaged.

Decidedly greater damage occurred in the unsterilized as compared with the sterilized soil. All plants in the control cans remained free from lesions.

EXPERIMENT 3.—The results thus obtained with pure cultures in sterile soil show definitely the power of the fungus to produce lesions on potato stems through a range of soil temperature from 9° to 27° C. The conditions, however, under which the data were obtained were obviously artificial and can provide but a very general idea as to what might be obtained in nature. With the view of obtaining a more accurate index to the practical problem, natural means of soil infection were used in this experiment.

Unsterilized soil was again used in one series of 16 cans, 2 cans at each temperature. A second series was provided with steam-sterilized soil. As in experiment 2 both types of soil were represented in the controls.

As the Irish Cobbler potatoes used for seed were free from sclerotia, two small Early Ohio tubers well covered with sclerotia and without treatment were placed in the bottom of each can and covered with approximately 1 inch of soil. Three halves of Irish Cobbler tubers, previously treated, were then placed on this surface and covered to the regular depth of 5 inches. All the controls were arranged in exactly the same way except that the potatoes used were treated before planting. Observations made 42 days after planting are recorded in Table III.

The plants, on the whole, exhibited a more severe type of injury in the sclerotia-inoculated soil than was obtained with the pure culture of the fungus in experiments 1 and 2. The range of temperature through which lesions occurred was approximately the same as that found in experiment 2. The greatest degree of severity was found at 15° and 18° C.

TABLE III.—*Effect of growing Irish Cobbler potatoes in soil inoculated with sclerotia of Corticium vagum and held at various temperatures*

EXPERIMENT 3

Temperature (° C.).	Number of sets planted.	Number of stems grown in uninoculated soil.	Stems grown in inoculated soil.						
			Total number.	Number slightly injured.	Number severely injured.	Number cut off.	Number uninjured.	Percentage injured.	Intensity of injury (points).
9	3	8	34	.....	6	5	23	32.3	79.3
11.6	3	5	41	.....	8	5	28	31.7	75.6
14.7	3	8	49	1	11	14	25	53.0	132.6
18	3	13	54	4	14	15	21	61.0	142.2
21	3	14	38	7	7	3	21	44.6	78.2
23.7	3	8	34	11	7	2	14	50.0	82.2
27	3	8	38	.....	4	.....	34	10.5	21.0
30	3	9	31	.....	.....	.....	31	.....	.....

The type of lesions produced on the stems in this experiment was identical with those obtained in the previous experiments from a pure culture of the organism. In no case were lesions found without the presence of the typical hyphae characteristic of the sterile stage *Corticium vagum*. The control plants were found to be free from both lesions and fungus.

The Early Ohio tubers used to introduce the inoculum had not passed through their dormant period. Sprouts from these made a growth of from ½ to 3 inches during the five weeks. When harvested, a number of these slow-growing stems showed distinct lesions only at the growing point. Further examination indicated that such lesions were initiated in the sinus or reentrant angle of the hook-shaped bud, at which point considerable quantities of mycelium were collected (Pl. 89, A). The

slow growth of the shoots and the protection offered in the sinus area apparently permitted the collection of hyphae and finally the killing of the bud or growing point of the stems. An explanation is thus suggested for the abundance of such localized tissue destruction at the lower temperatures where growth of the young shoot is seriously retarded. It further suggests a possible genetic relation between the growing-point injury and the lesions occurring elsewhere on the stem.

The results agree with those of experiment 2 in showing a decidedly higher percentage of diseased stems and a more severe type of lesion in the unsterilized than in the sterilized soil (Table IV and fig. 3).

TABLE IV.—*Percentage of diseased stems in sterilized and unsterilized soil*

EXPERIMENT 3

Temperature (° C.).	Unsterilized soil.	Sterilized soil.
9.1	[a] 50	12.5
11.6	50	14.2
14.7	72	33.3
18	90	34.8
21	52.3	35.8
23.7	28.9	13.3
27	23	4
30	.....	.....

[a] The water content of the unsterilized soil used in the experiment was found to be 20.4 per cent of its dry weight. No determinations were made of the change in the water relation of the soil due to sterlization.

EXPERIMENT 4.—This experiment differed from experiment 3 only in the use of Early Ohio seed. As adequate sclerotia occurred on the surface of the potatoes used for planting, the same tubers served both for an index and for the conveyance of the inoculum.

TABLE V.—*Effects of growing Early Ohio potatoes at various temperatures in soil inoculated with sclerotia of Corticium vagum*

EXPERIMENT 4

Temperature (° C.).	Number of sets planted.	Number of stems grown in uninoculated soil.	Stems grown in inoculated soil.						
			Total number.	Number slightly injured.	Number severely injured.	Number cut off.	Number uninjured.	Percentage injured.	Intensity of injury (points).
8.8	3	5	25	5	1	.....	11	24.0	28.0
11.8	3	10	33	10	5	.....	18	45.4	63.0
15.3	3	11	23	8	4	.....	11	52.1	69.6
18.2	3	12	22	3	5	2	12	45.5	86.6
20.8	3	9	24	5	2	1	16	33.3	49.7
23.7	3	9	25	7	3	.....	15	40.0	52.0
27.4	3	9	26	4	1	.....	21	19.2	22.9
30	3	9	24	.....	.....	.....	24	.....	.....

The results of this experiment, as related to temperature, agree essentially with those obtained in experiment 3 (Tables V and VI and fig. 4). The primary difference appeared in the fact that the highest percentage of diseased plants were found in the soil held at 15° C. When considered from the standpoint of total tissue destroyed, the high point apparently falls at 18°.

The percentage of infection of the Early stems was much lower and less uniform than that obtained with the Irish Cobbler stems in experiment 3.

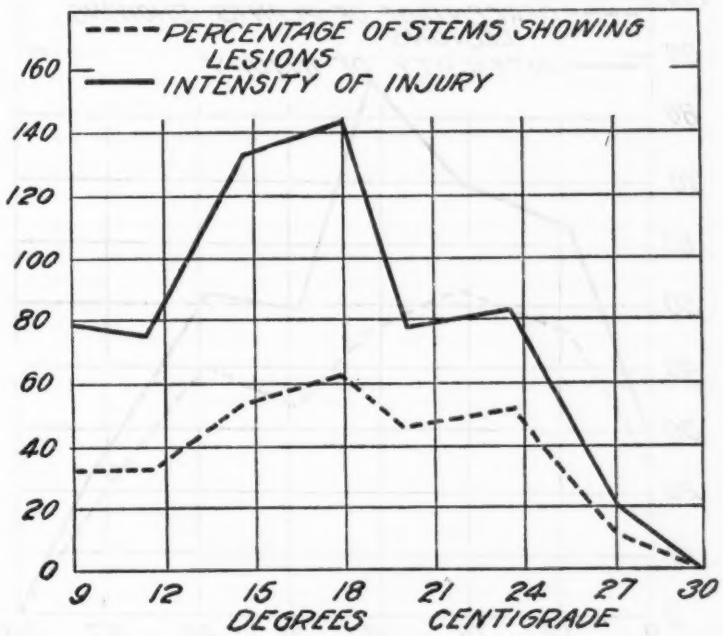

FIG. 3.—Relation of soil temperature to the severity and to the distribution of the injury caused on potato stems by *Corticium vagum* (experiment 3).

TABLE VI.—*Percentage of diseased stems in sterilized and unsterilized soil*

Temperature (° C.).	Sterilized soil.	Unsterilized soil.
8.8	30.0	30.0
11.8	26.6	61.0
15.3	22.2	71.4
18.2	.....	71.4
20.8	22.2	33.3
23.4	20.0	53.3
27.4	23.0	15.3
30	.....	.....

With the exception of the stems in one pot of sterilized soil, all control plants were found to be free from both lesions and fungus. The presence of the fungus in the one control pot resulted, apparently, from inadequate sterilization of the seed.

EXPERIMENT 5.—In this experiment, which was started at the time of early potato planting in Wisconsin, an attempt was made to approach as nearly as possible the exact conditions found in the field in normal potato culture. Surface soil was obtained directly from the field at the

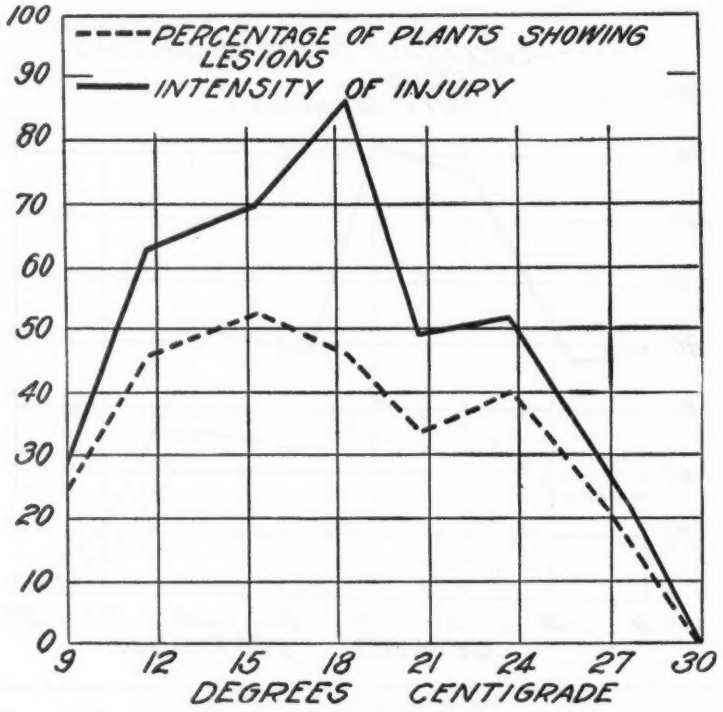

FIG. 4.—Relation of soil temperature to the severity and to the distribution of the injury caused on potato stems by *Corticium vagum* (experiment 4).

time of planting, May 17, and was placed, after mixing and without sterilization, into sterile cans. No serious modification of the water relation or the structure of the soil resulted. The soil was comparatively damp, showing a water content at the time of planting of 24.8 per cent of the dry weight.

All tubers used for seed were selected for a uniform and an abundant occurrence of sclerotia and for the absence of all bruises or scabbed areas which might function in the introduction of complicating organisms. In order to eliminate organisms loosely adhering to the surface of the

tubers used for soil inoculation, the latter were treated five minutes in a mercuric-cholrid solution (1 to 1,000). They were then washed free from the mercuric chlorid and planted. Tubers from the same lot, treated two hours in the standard solution, were planted for control. Three half tubers were planted in each can.

The plants were harvested June 15, 32 days after planting.

Under these more natural conditions lesions again occurred at from 9° to 27° C. No typical lesions were found in the soil held at 30°. The difference in intensity of injury at the various temperatures was even more distinctly marked than was found in the preceding experiments. At 24° and 27° the lesions were limited both in depth and area. Severe cortical injury resulted at 21°, and at 15° and 18° the entire cortex of many of the stems was totally destroyed (Pl. 91, A, B). Below 15° this type of critical injury again definitely decreased.

At the soil temperature of 21° C. and below, the growing points of many of the shoots were destroyed. As is shown in Table VII, this type of injury was slight at 21° but became very prominent at 18° and 15°. The highest percentage of stems showing the destruction of the primordia was found at the low temperature of 12° (Pl. 90; 91; fig. 5). In this latter respect experiment 5 differed from all previous experiments. The relation, however, was so definite as to indicate that similar results might be obtained in many cases under natural conditions in the field.

TABLE VII.—*Effects of growing Irish Cobbler potatoes at various temperatures in soil inoculated with sclerotia of Corticium vagum*

EXPERIMENT 5

Temperature (°C.).	Number of sets planted.	Number of stems grown in uninoculated soil.	Stems grown in inoculated soil.						
			Total number.[a]	Number slightly injured.	Number severely injured.	Number cut off.	Number uninjured.	Percentage injured.	Intensity of injury (points).
9.4	3	11	61	.....	8	17	36	40.9	109.6
12.2	3	11	65	3	14	31	17	73.0	190.9
15.0	3	13	62	2	16	24	20	62.4	158.6
18.2	3	8	64	4	22	23	15	76.4	182.5
21.4	3	9	51	11	20	3	17	66.6	117.5
24.4	3	16	49	13	15	.....	21	57.1	87.7
27.1	3	11	47	5	4	.....	40	19.1	27.7
30.3	3	38	47	2	1	.....	44	6.3	8.5

[a] The number of stems was determined on the basis of all stems arising from the tuber directly or as secondary shoots at or near the base of the primary stem (Pl. 90, 91). Comparatively few stems succeeded in getting through the soil at the lower temperatures.

TEMPERATURE RESPONSE OF THE POTATO PLANT IN UNINOCULATED SOIL

The available data on the temperature requirements of the potato secured by Orton (*9*, *10*) and Smith (*15*) from a study of the regional distribution of the plant and as expressed in terms of yield and general

freedom from disease must be considered as related primarily to its entire growing season. They provide no specific indications as to the relation of temperature to the various periods of the growth and development of the potato plant. So far as is known to the writer, no one has given close attention to the effect of soil temperature on growth of the potato during the first four or five weeks of its development, at which time the "Rhizoctonia" disease is most destructive.

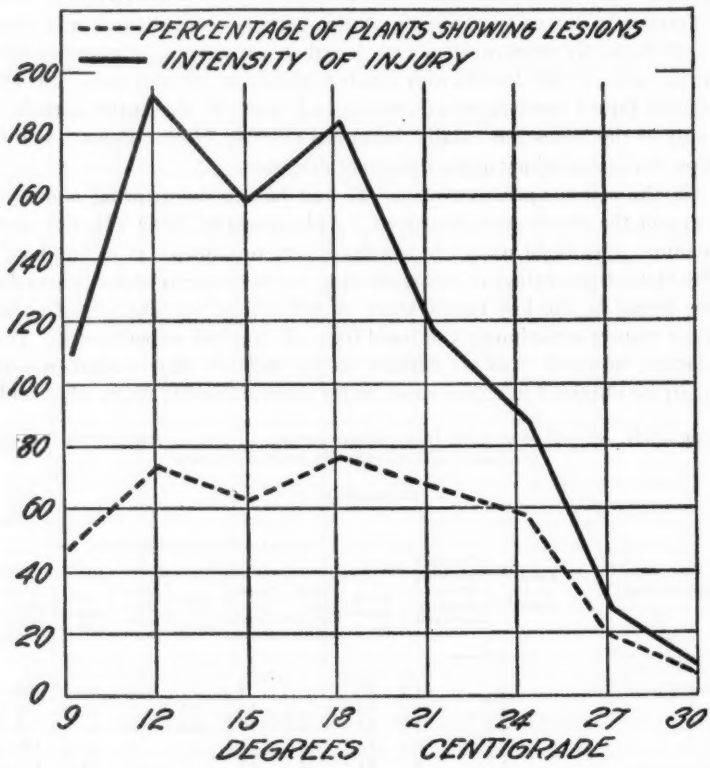

FIG. 5.—Relation of soil temperature to the severity and to the distribution of the injury caused on potato stems by *Corticium vagum* (experiment 5).

In the course of the greenhouse experiments, observations were made as to the reaction of the normal potato plant at the various soil temperatures. The data are seriously limited by the fact that such observations were of necessity confined largely to an early period of growth of a comparatively small number of control plants. The results, however, appear of sufficient interest to warrant their inclusion.

The data from the various experiments emphasized somewhat clearly the importance of the rate of growth of the young shoot during the period

in which the growing point is exposed to the fungus in the soil. This relation was determined with a fair degree of accuracy by the rate at which the plants appeared through the soil at the various temperatures. Uniformly in all the experiments the plants at 24° C. came up first. These appeared after a period of from 18 to 25 days, depending upon the vigor and state of dormancy of the tubers used for seed. In general, the plants in soil held at 18°, 21°, and 27° appeared from 2 to 5 days later than those at 24°, while those grown at 9° and 12° were delayed as much as 10 to 15 days. The plants at 30° were very irregular in their growth and in a few cases were as seriously retarded as plants at 12°.

A quantitative expression of the time estimate of the rapidity of growth is found in the data presented in Table VIII. The results are in general representative of the growth obtained in all the different experiments where adequate time was allowed before removing the plants. A decidedly different growth relation is shown at the various temperatures with the change of the seat of action from the tubers and growing points underground to the leaves and growing points above ground. The measurements obtained on December 2, 33 days after planting, together with the appearance of the plants December 15, as shown in Plate 88, B, indicates an optimum soil temperature somewhere near 18° C. for the latter periods of potato growth. This, in general, agrees with the conclusions of Orton (*9*) and Smith (*15*).

TABLE VIII.—*Effect of various soil temperatures on the rate of growth of the normal potato plant at different stages in its early development* [a]

Date.	Age of plants.	Average height of plants at various temperatures.							
		9.5° C.	12° C.	15.2° C.	18° C.	21.4° C.	24° C.	27.2° C.	30.5° C.
	Days.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Nov. 25	25	Not up	Not up	1.4	2.1	2.7	3.2	2.5	2.0
Dec. 2	33	Just up	2.6	4.3	5.8	5.0	4.8	3.8	3.2
Dec. 15 [b]	46								

[a] The figures represent the height of the plant above the soil.
[b] Plate 88, B, shows the relative heights of plants at this date.

The most interesting results were obtained with respect to the effect of the high temperatures upon the general morphology of the potato plant. Uniformly, at 30° C. the plants showed a decided swelling of the underground stems (Pl. 93, B). This feature was accompanied by a repression of the stolons and by what appeared to be a compensating development of leafy structures or deformed branches at the underground nodes. Excessive branching also occurred at or near the apical region of the stem just as the latter emerged through the soil. Upon further growth these branches gave a decided rosetted appearance to the plants. The aerial branches were in general very slender, with shortened internodes, and bore very small, narrow leaves which

frequently lacked the normal segmentation. These latter relations are well shown in Plate 88, A, B, and is further expressed together with other relationships in Table IX.

TABLE IX.—*Measurements on Irish Cobbler plants, grown in uninoculated soil, showing the effects of soil temperature upon the development of the various organs 33 days after planting*

	9.5° C.	12° C.[a]	15.2° C.	18° C.	21.4° C.	24° C.	27.2° C.	30.5° C.
Number of plants measured	.....	.....	6.0	5.0	9.0	6.0	9.0	5.0
Average height of shoots..(in.)	.....	2.1	4.3	5.8	5.0	4.8	3.8	3.2
Average diameter of shoots (mm.)	.....	.....	7.5	8.75	7.5	7.5	6.5	5.0
Average width of leaves (mm.)	.....	.....	37.5	38.0	32.0	26.0	17.0	14.0
Number of leaves per plant	.....	.....	4.5	5.0	5.1	7.0	7.0	6.0
Average number of leaves per inch of height	.....	.....	1.0	.86	1.02	1.45	1.45	1.89

[a] At the time the data were taken the plants in the 12° C. tank were just through the soil but not sufficiently high to give reliable measurements.

At 30° C. excessive lenticle development resulted on both the underground stems of the growing plant and upon the mother tubers. This response, no doubt, appeared as results of the excessive respiration occasioned by the high temperature of the soil.

The various abnormal responses were not confined to the soil maintained at 30° C. but were found in a much less exaggerated form at 24° and 27°. Both these latter temperatures appeared decidedly unfavorable for the continued growth and development of the plant under the conditions obtained in the experiments. The plants grown at 9° and 12° showed a development which might be considered below normal and exhibited more or less spindling shoots, long internodes, few leaves, and slight yellowing. No tendency to direct tuberization was shown as was found by Vochting (17) to occur at 6° and 7°. On the whole, the plants showed the greatest vigor during the latter period of their early growth in the soil held at 18° and 21°. In parallel experiments which were conducted on the potato at the same temperatures and in which plants were grown approximately to maturity, the soil temperature of 15° to 18° proved more favorable than any of the higher temperatures for the plants to withstand the continued artificial conditions imposed in the experiments.

FUNGI CONCERNED IN PRODUCTION OF LESIONS

In drawing conclusions from the results obtained from the different experiments in which pure culture and sclerotial methods of soil inoculation were used, the question immediately arises as to whether in the two cases we are dealing with one and the same pathogen or strains of the same pathogen or whether in the case of sclerotia-inoculated soil

we are concerned with one or a group of organisms possibly widely different and capable under the conditions of the experiment of producing results similar to those secured with the pure culture of *Corticium vagum* described as strain 201. These questions were kept constantly in mind, and special studies were made during the progress of the work.

It is evident from the uniform freedom of the control plants from disease that the organism or organisms responsible for the lesions occurring in the inoculated soil were introduced by the various methods used and were not resident in the soil in which the potato plants were grown. In but two experiments did typical lesions occur on any control plants, and in each of these as reported the threads of "Rhizoctonia" were abundantly and unmistakably present.

The lesion on the potato stems in the sclerotia-inoculated soil were found to be indistinguishable from those produced with the pure cultures of the fungus in sterile soil. With both methods of inoculation the fungus was found constantly associated with the resulting cankers. When there was doubt the presence of the fungus was determined either by the use of the compound miscroscope or by cultural methods. During the studies isolations were also made from 138 lesions produced in sclerotia-inoculated soil. Seventy-eight per cent of these yielded pure cultures of *Corticium vagum*. From the remaining 22 per cent this fungus was obtained so intimately associated with other fungi that separation was not attempted. A somewhat higher percentage of pure cultures of the fungus was obtained from lesions produced in the artificially inoculated soil.

A further study of the casual relation of *Corticium vagum* to the lesions produced in soil inoculated with sclerotia was made by removing all the sclerotia from 25 of the potatoes selected from the same seed as was used in experiment 5. The tubers were then treated for two hours in the standard solution of mercuric chlorid and planted in contact again with the scleroti in steam-sterilized soil. The pots were then held at temperatures from 18° to 22° C. The results were comparable in every way with those obtained in the sclerotia-inoculated soil in experiment 5.

With the partially sterilized tubers in experiment 5 the same type of lesions was obtained as with the pure culture of the fungus and with untreated tuber-borne sclerotia. Finally, the temperature data in general supported the conclusion that in the two methods of inoculation the same fungus or closely related strains were responsible for the production of the type of lesions concerned. It must be kept in mind, however, that with the introduction into the soil of a potato the surface of which is covered with a large number of organisms, we are introducing complicating factors; and it seems quite probable that some of these organisms may be important factors in increasing the severity of resulting lesions, or on the other hand, they may possibly inhibit the pathogenic

action of *Corticium vagum* on the potato stems. The recent work of Edson and Shapovolov (*3*) is interesting in this connection.

From the foregoing studies and from previous work, much more extensive than outlined here, it becomes evident that the sterile stage of *Corticium vagum* is definitely capable, under natural conditions of potato culture, of producing all the primary effects on the potato plant which have been attributed to it, and that under normal field conditions other organisms, whatever they may be, are possibly of secondary or of more or less minor importance. Granting their pathogenic action under extreme conditions, we have no conclusive evidence as yet of their importance in general potato culture. It is evident, however, that this problem stands much in need of investigation.

DISCUSSION

The results obtained both with pure culture and with the natural method of soil inoculation disclosed the general fact that the organisms concerned are capable of producing lesions on potato stems over a wide range of temperature from 9° to 27° C. *Corticium vagum* becomes a serious factor in potato production, however, only at soil temperatures below 24°. While 18° proved the most favorable temperature for the pathogenic action of the fungus, it appeared evident that any wide variation in the numerous factors involved might result in a temperature requirement for maximum pathogenicity at any point between 15° and 21°. No definite critical temperature such as has been obtained for other soil organisms by Gilman (*4*), Tisdale (*16*), and Johnson and Hartman (*5*) was found to exist at the lower range of temperatures maintained in the experiments. In all cases within the range of temperature favorable for its pathogenic action *Corticium vagum* proved to be a very dangerous parasite. This range approximates very closely that found most favorable for the best development of the potato plant.

The divergence of the percentage and the intensity curves at the lower temperatures reveals a wide difference between the percentage of stems showing lesions at the various temperatures and the degree of injury to the plant subsequent to infection. This difference was found to be due both to a more severe type of tissue destruction subsequent to the initial infection at the lower temperature and to an attack on and frequent destruction of the growing point of the young shoots. This latter type of injury was seldom found at or above 21° C., while at temperatures lower than 21° it assumed decidedly serious importance.

At 18° C. the fungus exhibits a maximum of activity both in the number of stems infected and in the degree of injury subsequent to infection. The exact relation of soil temperature to the divergence between these two processes at 21° and 24° as compared with the lower temperatures is not clear. It is possible that the rapid rate of growth

of the young shoots with concomitant increased rate of cellular differentiation enters in as an important factor in lessening the degree of injury at the higher temperatures. Again, the depth and the spread of lesions may be closely associated with the growing-point injury which is most severe at the lower temperatures. On the other hand, it is very probable that decreased tissue destruction is in part at least a result of a direct inhibitive action of the higher temperature upon the physiological activities of the fungus. Balls (*2*) noted a similar decreased parasitic activity of "sore-shin fungus" (*Rhizoctonia solani*) on the cotton plant and postulated an inhibiting factor "X" in the form of a by-product of fungous metabolism. He assumes that this accumulates at the higher temperatures and limits both infection and subsequent action of the fungus on the cotton tissues. Whether or not such explanation is justified, it is evident that it does not apply to the inhibited parasitic activity which resulted in a lesser degree at temperatures below 18°. A determination of the type and the rate of enzym secretion by the fungus at the various temperatures would undoubtedly aid greatly in understanding the problem.

The relation of the temperature of the soil to the destruction of the primordia of the young shoots appears more clear. Evidence has accumulated which indicates that this type of injury depends largely upon an opportunity for the mycelium to accumulate in the sinus of the bud of the young stem in contact with the delicate primordium (Pl. 89, A). At the lower temperatures the rate of growth of the young shoots is so retarded as to increase definitely the time of exposure of the young buds to the action of the fungus in the soil. The opportunity for the accumulation of the mycelium in the growing points and for subsequent tissue destruction is thereby greatly increased.

The increase in the number of stems noted at the lower temperatures is doubtless closely associated with the growing-point destruction and must be considered as the result of a peculiar balance between the host and the parasite which is ultimately conditioned by the temperature of the soil. Granted the presence of a virulent "strain" of *Corticium vagum*, it appears evident that the number of stems which survive and finally appear through the soil in an infested area will depend to a large extent upon the duration of temperatures favorable or unfavorable for the pathogenic operation of the fungus. When a favorable temperature is maintained for a considerable period not only will large numbers of primary growing points be destroyed but secondary and even tertiary buds may succumb to the attack of the fungus, thus decreasing the number of successful stems per hill. When, however, the period of soil temperature favorable for pathogenicity of the fungus is short, resulting secondary stems may escape injury; and as two or even more may start from a single injured sprout, a decided increase in the number of stems is

made possible. On the other hand, where total absence of temperature favorable for the action of the fungus occurs, as was found in the higher temperatures, no effect on the number of stems will result.

SUMMARY

(1) The power of the sterile or "Rhizoctonia" stage of *Corticium vagum* to produce lesions on potato stems varies greatly in different localities and under varying soil and climatic conditions. A study of the factors affecting the pathogenic action of the fungus is essential to a better understanding of the disease and to the formulating of effective control measures.

(2) *Corticium vagum* causes the greatest damage to the potato at a very early stage in the development of the host, probably before the young shoots appear above the soil. Two types of stem injury are especially recognized—the cankering of the cortex of the basal portions of the stem and the destruction of the primordia of the young shoots before they push through the soil. This latter type is considered the more serious.

(3) Stem lesions produced by pure cultures of *Corticium vagum* were indistinguishable from those obtained in soil inoculated with the sclerotia of the fungus. Other fungi are recognized as possible complicating factors under natural conditions. The fungus attacked the potato stems more vigorously in unsterilized than in steam-sterilized soil.

(4) The percentage of stems injured does not give a true index to the degree of damage produced by the fungus. The intensity of injury is used to express the relative value of the different soil temperatures.

(5) The various strains of *Corticium vagum* introduced into the soil as a pure culture or as sclerotia produced lesions on the basal portion of potato stems throughout the same range of soil temperature of from 9° to 27° C. The greatest damage occurred between 15° to 21°, while 18° proved to be the most favorable temperature for tissue destruction as well as for growing-point injury. Serious destruction of tissue resulted at 9°. The severity of attack decreased rapidly above 21° until at 24° *C. vagum* proved to be of minor parasitic importance. Few typical lesions occurred at or above 27°.

(6) Growing-point destruction was confined to temperatures at or below 21° C. At 21° this type of injury was slight. On the other hand, it was found that it may reach its maximum expression at a temperature as low as 12°.

(7) Growing-point injury is dependent upon the rate at which the young shoots grow through the soil. At temperatures above 21° C. the rapid growth of the potato, together with the decreased pathogenic power of the fungus, was found to permit the primordia of the young shoots to escape uninjured.

(8) The degree of growing-point destruction appeared as an important factor in determining the increase or the decrease from the normal of the number of stems above the soil in an infected area.

(9) No "critical temperature" for the pathogenicity of the fungus on the potato appeared at the lower range of temperature used.

(10) The temperature requirements of the potato plant were found to vary with its different stages of growth. The young sprouts, while in the soil, grew most rapidly at 24° C. Growth was greatly retarded at 15° and below. At soil temperatures above 24° the plant exhibited such abnormal responses as excess branching, shortening of the internodes, decreases in segmentation of the leaves, and decrease of the diameter of the stems. A soil temperature of approximately 18° proved optimum for the later and continued development of the potato plant.

(11) The soil temperature of 18°C. found most favorable for the pathogenic action of *Corticium vagum* approximates closely the temperature of the soil optimum for the general development of the host.

(12) Soil temperature data obtained from field studies with the potato and from greenhouse experiments with the pea and the bean will be published in a later paper.

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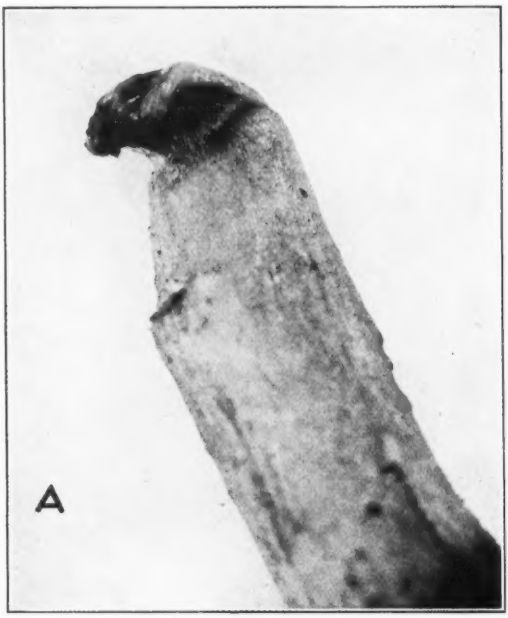
PLATE 88

A.—Irish Cobbler potato plants grown in soil held at constant temperatures of 18° and 27° C. The effect of the higher temperature is shown in the smaller size and increased number of leaves, the shorter internodes, and the decreased diameter of the stem. Comparative figures are given in Table IX.

B.—Series of Irish Cobbler potato plants grown in soil held at soil temperatures of 9°, 12°, 15°, 18°, 21°, 24°, 27°, and 30°. Plants in A were taken from a different but parallel series. Plants 46 days old.

A

B


A

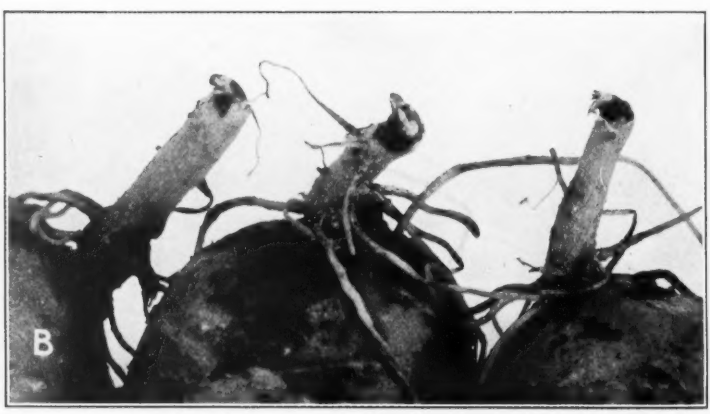

B

PLATE 89

Early Ohio potato shoots showing characteristic sinus injury. With normal seed, injury of this type occurred only at a soil temperature of 21° C. and lower. The tubers, however, from which these shoots were grown had not passed completely through their dormant period. Due to the resulting slow growth and to the increased length of exposure of the bud to the fungus in the soil, injury occurred at a temperature of 24°. (See experiment 3, p. 468–470.)

A.—Shoot showing the characteristic sinus injury and the accumulation of the mycelium of *Corticium vagum* in the sinus at the point of attack.

B.—Three additional shoots of the same seed, showing more advanced and progressive stages of the growing-point injury.

PLATE 90

Plates 90 to 93, showing plants from experiment 5, representing the type and the degree of injury to Irish Cobbler potato stems which occurred in sclerotia-inoculated soil (unsterilized) held at constant temperatures ranging from 9° to 30° C., as specified in the respective legends.

A.—Plant grown at a soil temperature of 9 °C. Twenty-seven per cent of the growing points were destroyed at this temperature.

B.—Plant grown at a soil temperature of 12°. Forty-seven per cent of the growing points of the plants held at this temperature were destroyed. Greater tissue destruction also occurred than at 9°.

1 2
A
B

3
4
A
B

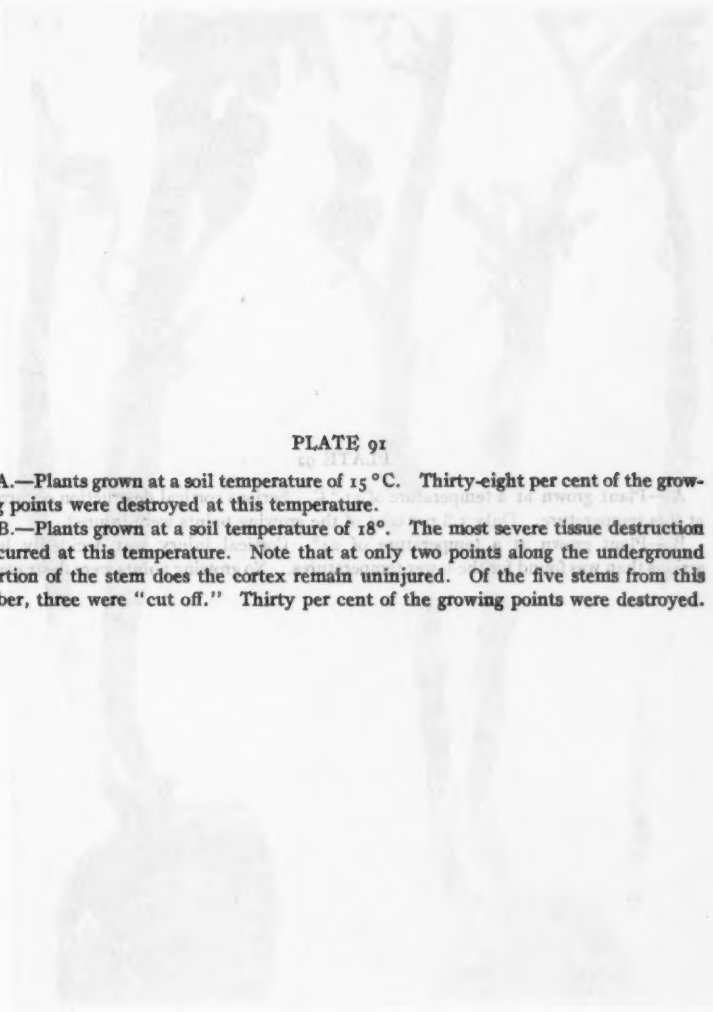


PLATE 91

A.—Plants grown at a soil temperature of 15 °C. Thirty-eight per cent of the growing points were destroyed at this temperature.

B.—Plants grown at a soil temperature of 18°. The most severe tissue destruction occurred at this temperature. Note that at only two points along the underground portion of the stem does the cortex remain uninjured. Of the five stems from this tuber, three were "cut off." Thirty per cent of the growing points were destroyed.

PLATE 92

A.—Plant grown at a temperature of 21° C. Serious cortical destruction occurred at this temperature. Only 5.8 per cent of the growing points were injured.

B.—Plant grown at a temperature of 24°. Cortical injury was decidedly less serious than was found for the lower temperatures. No growing points were destroyed.

A
B

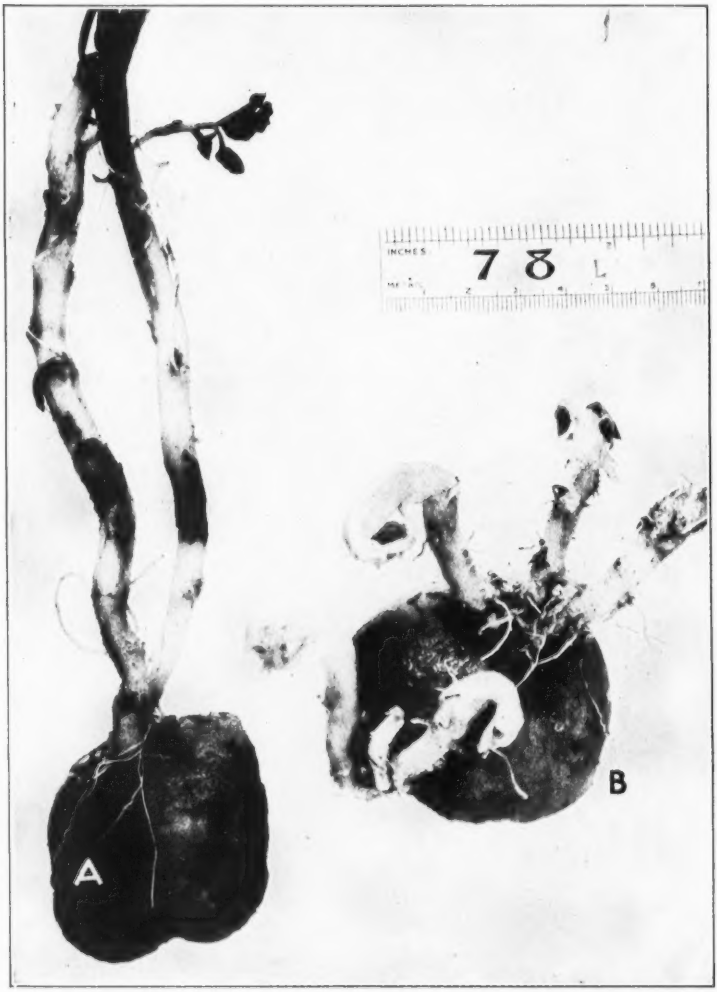

INCHES
7 8
A
B

PLATE 93

A.—Plant grown at a temperature of 27 °C. Slight cortical injury occurred on 9 of the 47 plants grown in inoculated soil.

B.—Plant grown at a temperature of 30°. No typical lesions were found at this temperature.

FURTHER EXPERIMENTS IN FIELD TECHNIC IN PLOT TESTS [1]

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INTRODUCTION

In a former paper (*2*)[3] results of determinations of the effect of 18-inch alleys on the outside and inside border rows of oats, wheat, and barley varieties were made available. At that time no data appeared to be available regarding the possible border effect on rows farther within plots than the second 6-inch drill row. To secure data on this point, determinations of yield for the first, second, and third 6-inch drill rows from either side of each plot were made in 1918.

In the determinations of border effect with varieties, the rate of seeding as well as other factors were necessarily as nearly identical as it was possible to make them.

Cultural and rate of seeding tests on plots surrounded by alleys and roadways are being carried out yearly. To what extent does border effect influence results in such trials where all plots are sown with the same variety and where other conditions such as methods of preparation of the seed bed, rates of seeding, etc., are varied? In order to secure data on border effect in rate of seeding tests, determinations were made in 1918.

The data secured for the purpose of aiding in the interpretation of results in Minnesota may be of interest to scientific workers elsewhere and, therefore, are made available.

REVIEW OF LITERATURE

The need of using methods in conducting plot tests and in the interpretation of results from them which may be relied on to give close approximation to the actual results has been given considerable attention. The subject has been considered mainly from four standpoints, (1) selection of the location for the plots, (2) laying them out, which necessitates the consideration of how many repetitions, size and shape,

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[2] The writer acknowledges the cooperation of Prof. T. E. Odland, formerly agronomist at the Morris Substation, and Superintendent P. E. Miller, of the same institution, for growing and caring for the crop at that location, and Prof. F. W. McGinnis, assistant professor of farm crops at University Farm, for aid in computing the results.

[3] Reference is made by number (italic) to "Literature cited," p. 497–499.

number and location of controls, alleys between plots, etc., (3) the technic of harvesting and thrashing, and (4) the interpretation of the results.

Carleton (*4*), Piper and Stevenson (*17*), Thorne (*20*), and others have considered practically the entire subject in a general way and have offered suggestions looking toward the improvement of technic in plot tests. Lyon (*12*) used original data and that of others to emphasize some of the essential considerations in plot tests.

Harris (*8*) has used the original data of Montgomery (*15*) and that of Mercer and Hall (*13*) to show the need of considering variations in the soils of fields used for experiment when interpreting the results from them. In a later article (*9*) the same writer used the original data of Kiesselbach (*11*) and that of others to further demonstrate heterogeneity of soil in fields selected for their uniformity. Emphasis is laid on the necessity for greater care in the technic of plot tests and on the use of statistical methods in the analysis of the data.

Surface and Pearl (*19*) propose a method for use in correcting for soil heterogeneity in plot tests. This method is useful only when the plots are located in blocks several in extent each way.

Smith (*18*) emphasizes the value of replication and of carrying the tests over a period of years in securing dependable results. He also mentions that the plants in one plot may have an influence on those growing in adjacent plots. Montgomery (*14*) has shown that the plants of one variety may have a considerable effect on those of another variety growing near. Hayes and Arny (*10*) report on the effect that plants in rod rows spaced a foot apart may have on each other.

That the yields of plots flanked by cultivated alleys are higher because of the effect of the additional space on the outside rows has been shown by Arny and Steinmetz (*2*). The higher yields of border rows as compared with central rows in plots flanked by alleys has been shown by Arny and Hayes (*1*), and in addition, the effect of border rows on the rank of particular varieties in tests is emphasized.

Since the publication of the earlier article (*2*) several papers which relate to this subject have come to the attention of the writer. Fletcher (*7*) reports that crops growing on the border of a fallow yielded at a rate as much as 10 times as great as the rate in the center of the plot. This is accounted for largely by the absence of toxic substances on the fallow side of the outside rows. The width of the fallow area is not mentioned.

Chittenden (*5*) gives results for turnips planted in plots 33 feet long and 7 feet 6 inches wide. The rows of turnips were 18 inches apart, and the outer rows of any two plots were 4 feet 6 inches apart. This gives 36 inches of additional space to the two outside rows flanking each alley. The rows extended east and west. For the crop planted May 25 and weighed July 29, the weights of the tops of the outer rows averaged 94 as compared with the middle row's weight of 78, both on the basis of 100 for the heaviest row. On the same basis, the roots from the outside rows aver-

aged 91 and the middle row 83. In another trial, four rows of turnips each 18 inches apart were sown July 16 in plots 13 feet by 9 feet with 9 feet 6 inches as the distance between the outside rows of any two plots. These were harvested September 28. Here on the basis of 100 for the heaviest row of each plot, the roots from the outside rows yielded at the rate of 95 and the inside rows at the rate of 70. Discarding the plants in the outside rows before estimating yield is recommended.

In a later paper the same writer (*6*) reports that potatoes in 3-foot rows, with alleys several feet wide on one side and from 4 to 5 feet wide on the ends, showed marked border effect. The rows extended north and south. Inner row No. 1, next to the outer row, yielded 72, and the third row in the plot yielded 72, as compared with 100 for the outside rows. Yields of the end plants of the rows was as 100 to 82, as compared with the average of the other plants in the same rows. In other trials end plants yielded 100 to 87, 100 to 92, and 100 to 88.4, respectively, as compared with the average for the other plants in the same rows. Corner plants—those having additional space in two directions—yielded 100 to 79, as compared with the other plants in the outside rows, and 100 to 57, as compared with the inner plants. The statement is made that in yield trials at Wisley outer rows are planted which do not essentially belong to the plots. They are to protect the rows of the plants from border effect.

Wheeler (*21*) notes that in Germany at some locations provision had been made to prevent border effect, and that in some experiments at the Rhode Island Station border effect was eliminated by removing a strip 3 feet wide on the sides and 6 feet wide on the ends. This width was decided on because the area remaining was then $^1/_{10}$ acre.

Bedford and Pickering (*3*) in field tests found the weights of the entire plants in outside rows to be heavier than the weights of the produce from the inner rows. The relation in percentage was as follows: Mustard, outside 297, 201, and 200, as compared with 100 per cent for the inner rows; wheat at Ridgemont, outside 131, inside 100; wheat at Woburn, outside 204 and 161, inside 100; barley at Harpenden, outside 126, inside 100. On plots manured from 100 to 300 tons per acre the outside rows of mustard were 190, as compared with the inner 100; on land less heavily manured the outside were 228 and the inside 100. From these results the authors conclude that, under ordinary circumstances, approximately one-fourth of the border effect is due to increased food supply and three-fourths to decrease in toxic effect.

The observation is also made that with the mustard plant the border effect did not extend beyond 6 inches from the edge of the plot, no effect in the second rows being noticed when the rows were 9 inches apart. The width of the alleys or fallow spaces between plots is not mentioned.

TECHNIC OF THE EXPERIMENT

The determinations of yield to indicate the effect of alleys on first, second, and third rows on either side of each plot were made on the wheat, oat, and barley varieties at University Farm.

A rate of seeding test for oats has been conducted at University Farm for a number of years. The rates used vary from 48 to 112 pounds per acre, which gives a wide variation in the number of seedlings per acre in the spring and in the number of culms per acre at maturity. This material served for the purpose of border effect determinations, as well as for that which it was originally outlined. The various seedings, both in the variety tests and in the rate of seeding tests, are made on the same day, as far as possible, usually in early April, and the grain is harvested during the last week in July or the first week in August.

The soil at University Farm is a Hempstead silt loam, which is not representative of any large area of the State. In order to secure a variation in soil and other environment, the rate of seeding test was duplicated at the Morris Substation, which is located on a fine silt loam of Young Gray Drift formation. This is a soil more representative of a large area of the State than that on which the University Farm is located.

There were four regularly distributed plots of each variety of oats, wheat, and barley at University Farm. In the rates of seeding tests at the Morris Substation there were 3 plots of each rate except the 96-pound rate, of which there were 5 additional used as controls. At University Farm there were 2 of each rate on 5 different methods of seedbed preparations, making 10 in all for each rate.

At Morris the plots were made up of 12 six-inch drill rows, a total width of 6 feet. The length was 130 feet. At University Farm the plots were made up of 17 six-inch drill rows, a width of 8.5 feet. For the variety test the length was 129 feet, and for the rate of seeding test 132 feet. The borders on the ends of the plots next to the roads were removed accurately before harvest by trimming to a line established by a wire stretched shortly after planting.

Alleys 1½ feet wide extended between each two plots. They were cultivated to keep them reasonably free from weeds. The variety test plots extended north and south, and the rate of seeding plots at both locations extended east and west.

At Morris the series on which the test was conducted had been in meadow the year previous. Grain crops appear to be retarded, in some instances, following meadow as compared with following corn or a grain which has followed corn. The latter part of the growing season was without rainfall, which made conditions for the grain crop still less satisfactory. The University Farm tests followed corn in regular rotations, and the rainfall during the growing season was ample.

In the variety tests three rows on either side of each plot were harvested separately, bound and tagged. They are referred to as outside border, middle border, and inside border rows, respectively. In the rates of seeding tests, two border rows were removed from either side of each plot in turn, bound and tagged. They are referred to as outside and inside border rows. In both tests the rows remaining after the various border rows were removed are referred to as central rows. They were harvested with the binder. At thrashing time each row or rows, in the case of the central areas, were thrashed with a small machine, and the grain was weighed.

The sizes of the areas from which yield determinations were made are given in Table I.

TABLE I.—*Areas from which yields were determined*

Location.	Number of 6-inch drill rows.	Dimensions of areas.	Part of an acre.
Morris Substation	1	6 inches×130 feet	1/670.15
	8	4 feet×130 feet	1/83.77
	10	5 feet×130 feet	1/67.015
	12	6 feet×130 feet	1/55.84
University Farm (rate of seeding test)	1	6 inches×132 feet	1/660
	13	6.5 feet×132 feet	1/50.77
	15	7.5 feet×132 feet	1/44
	17	8.5 feet×132 feet	1/38.82
University Farm (variety test)	1	6 inches×129 feet	1/675.35
	11	5.5 feet×129 feet	1/61.40
	13	6.5 feet×129 feet	1/51.95
	15	7.5 feet×129 feet	1/45.02
	17	8.5 feet×129 feet	1/39.73

In order to secure the yields of the various plots with no border row removed, one removed, two removed, and (for the variety test) three removed, the weights of all portions of each plot were added together to secure the yields with no border rows removed. Likewise for the variety test the weights of the central rows and the two middle border rows were added to secure the yields with the outside border rows only removed, and for the rate test the inside border rows were added. In the variety tests the weights of the central rows and those of the inside border rows were combined to secure the yields of the plots with two border rows removed. The yields for the variety plots with three border rows removed and the rates of seeding plots with two border rows removed were computed from the weights of the grain from the central rows. The total weight of grain from the central rows was divided by the number of rows in order to secure the average yield for these rows. All computations have been checked.

EFFECT OF CULTIVATED ALLEYS ON YIELDS OF DIFFERENT PORTIONS OF PLOTS IN VARIETY AND RATE OF SEEDING TESTS

Examinations of the yield data as given in Table II for the rate of seeding tests with oats grown at Morris on sod land and under comparatively dry conditions show that at each rate the outside border rows yielded very much higher (an average of 233.6 per cent) than the inside border rows, which in turn produced at a higher rate (an average of 139.7 per cent) than the central rows.

TABLE II.—*Average yields in bushels per acre of oats from rate of seeding trials harvested from border drill rows spaced 6 inches apart removed from either side of plots 6 by 130 feet at the Morris Substation and 8.5 by 132 feet at University Farm and from the central 8 and 13 rows, respectively, which remained after the removal of border rows*

Source.	Number of rows or plots.	Yield in bushels per acre and in percentage based on the yields of the central rows sown at the rate (in pounds per acre) of—					Average yield per acre.
		48	64	80	96	112	
Morris Substation:		*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*
Outside border rows	40	84.1	99.6	105.9	104.1	103.0	99.3
Inside border rows	40	56.2	59.4	68.6	58.6	53.4	59.2
Central 8 rows	20	36.8	41.2	45.8	45.4	43.4	42.5
University Farm:							
Outside border rows	100	142.9	152.4	162.9	164.1	170.7	158.6
Inside border rows	100	70.3	62.4	72.2	81.1	77.4	72.7
Central 13 rows	50	72.3	72.2	76.1	79.3	75.5	75.1
Morris Substation:		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Outside border rows	40	228.5	241.7	231.2	229.3	237.3	233.6
Inside border rows	40	152.7	144.2	149.7	129.1	123.0	139.7
Average central rows	160	100.0	100.0	100.0	100.0	100.0	100.0
University Farm:							
Outside border rows	100	197.6	211.1	214.1	206.9	226.1	211.2
Inside border rows	100	97.2	86.4	94.8	102.3	102.5	96.6
Average central rows	650	100.0	100.0	100.0	100.0	100.0	100.0

At University Farm, under more favorable growing conditions, the outside border rows yielded on an average 211.2 per cent of the yield of the central rows. The inside border rows more often yielded less rather than more than the average of the central rows. In the 64-pound rate, the abnormally low average is due to a chance combination of low-yielding rows in this particular rate of seeding.

For the work with the varieties at University Farm the data for the 1917 work are included here in order that comparisons may be more easily made. In 1918 the outside border rows yielded considerably higher than the middle, inside, or central rows for all three crops. The middle and inside border rows of the oat and wheat crops yielded practically equally, whereas for the barley crop there is a difference of approximately 5 bushels between the two yields. Both the middle and

inside border rows yielded approximately 5 bushels higher than the average for the central rows.

Considered on the percentage basis the border effect, in 1918, on the outside rows was slightly higher for the oat and wheat crops and considerably lower for the barley crop than in 1917. The most striking difference in the results for the two seasons is that in 1918 the effect of the alleys for each of the three crops is much less apparent on the second rows (the middle border rows in 1918 and the inside border rows in 1917) than it was in 1917. The average in percentage for the three crops is 115.03 in 1918 as compared with 140.93 in 1917. In 1918, the third rows from the outside yielded approximately 5 bushels more than the average for the central rows for each of the three crops. Stated in percentages, the yields of the third rows from the outside are 106.1 for the oats, 113.7 for the wheat, and 108.6 for the barley, or an average for the three crops of 109.47 as compared with the average for the central rows.

TABLE III.—*Average yields in bushels per acre of varieties of oats, wheat, and barley harvested from border drill rows, spaced 6 inches apart, removed from either side of each plot and from the central rows remaining after the removal of the border rows, and the yields of the border rows in percentages based on the yields of the central rows*

Year and source.	Oats.		Wheat.		Barley.	
	Number of rows or plots.	Average yield per acre.	Number of rows or plots.	Average yield per acre.	Number of rows or plots.	Average yield per acre.
1918:		*Bushels.*		*Bushels.*		*Bushels.*
Outside border rows	112	142.8	56	73.1	72	99.9
Middle border rows	112	82.8	56	40.8	72	60.9
Inside border rows	112	80.0	56	39.8	72	55.8
Central 11 rows	56	75.4	28	35.0	36	51.4
1917:						
Outside border rows	88	131.97	40	55.00	32	97.73
Inside border rows	88	87.95	40	40.98	32	64.56
Central 13 rows	44	71.37	20	27.25	16	42.87
1918:		*Per ct.*		*Per ct.*		*Per ct.*
Outside border rows	112	189.4	56	208.9	72	194.4
Middle border rows	112	109.8	56	116.6	72	118.5
Inside border rows	112	106.1	56	113.7	72	108.6
Central 11 rows	56	100.0	28	100.0	36	100.0
1917:						
Outside border rows	88	184.9	40	204.4	32	238.0
Inside border rows	88	123.2	40	149.3	32	150.3
Central 13 rows	44	100.0	20	100.0	16	100.0

BORDER EFFECT AND THE INTERPRETATION OF YIELDS

It has been shown that the effect of alleys increases the yields of the outside border rows very materially and, in the majority of cases, increases the yield of the second and third rows also, but to a less extent. On small plots the effect of the increased yield of these border rows

results in materially higher yields for the plots when these rows are included as compared with results when they are removed before harvest (*2*). These increases in yields are given in Tables IV and V.

TABLE IV.—*Comparisons of increases in yields in bushels per acre and in percentage of oats sown at different rates in pounds per acre, with no border rows removed and with one border row removed from either side of each plot, based on the yields as 100 with two border rows removed*

Location and rates of seeding (in pounds per acre.)	Yield per acre.			Increase in yield per acre.			
	No border rows removed.	Outside border rows removed.	Both outside and inside border rows removed.	No border rows removed.		One border row removed.	
	Bushels.	*Bushels.*	*Bushels.*	*Bushels.*	*Per cent.*	*Bushels.*	*Per cent.*
Morris Substation:							
48	48.0	40.7	36.8	11.2	30.2	3.9	10.6
64	54.0	44.7	41.2	12.8	31.1	3.5	8.5
80	59.9	50.4	45.8	14.1	30.7	4.6	10.0
96	58.7	49.8	45.4	13.3	29.3	3.5	7.7
112	55.0	45.1	43.4	11.6	26.8	1.7	3.9
Average	55.1	46.1	42.5	12.6	29.6	3.4	8.1
University Farm:							
48	80.4	72.0	72.3	8.1	11.2	−0.3	−0.4
64	80.5	70.9	72.2	8.3	11.5	−1.3	−.2
80	93.0	75.7	76.1	16.9	22.2	−.4	−.5
96	88.8	79.5	79.3	9.5	12.0	.2	.2
112	86.9	75.8	75.5	11.4	15.1	.3	.4
Average	85.9	74.8	75.1	10.8	14.5	−.3	−.1

TABLE V.—*Comparison of the increases in yield due to border effect of oats, wheat, and barley in bushels per acre and in percentage based on the yields with three, two, and one, border row removed in 1918, and on yields with two and one border row removed in 1917, at University Farm, St. Paul, Minn.*

Crop.	Number of border rows removed from either side of each plot.	1918							1917				
		Yield per acre.	Increase in yield per acre over that secured with—						Yield per acre.	Increase in yield per acre over that secured with—			
			One border row removed.		Two border rows removed.		Three border rows removed.			One border row removed.		Two border rows removed.	
		Bush.	*Bush.*	*P. ct.*	*Bush.*	*P. ct.*	*Bush.*	*P. ct.*	*Bush.*	*Bush.*	*P. ct.*	*Bush.*	*P. ct.*
Oats	None	83.4	.....	.....	.....	.....	.....	.....	80.5	.....	.....	.....	.....
	One	75.9	7.5	9.87	8.2	10.90	9.1	12.25	73.6	6.9	9.38	9.1	12.74
	Two	75.2	.....	.....	.7	.93	1.6	2.15	71.4	.....	.....	2.2	3.08
	Three	74.3	.....	.....	.....	.....	.9	1.20	.....	.....	.....	.....	.....
Wheat	None	40.8	.....	.....	.....	.....	.....	.....	32.5	.....	.....	.....	.....
	One	36.4	4.4	12.09	5.0	13.97	5.7	16.24	29.2	3.3	11.30	5.21	19.05
	Two	35.8	.....	.....	.6	1.68	1.3	3.70	27.3	.....	.....	1.90	6.96
	Three	35.1	.....	.....	.....	.....	.7	1.99	.....	.....	.....	.....	.....
Barley	None	58.3	.....	.....	.....	.....	.....	.....	51.4	.....	.....	.....	.....
	One	53.2	5.1	9.59	6.3	12.12	6.9	13.42	45.8	5.6	12.23	8.5	19.81
	Two	52.0	.....	.....	1.2	2.31	1.8	3.50	42.9	.....	.....	2.9	6.76
	Three	51.4	.....	.....	.....	.....	.6	1.17	.....	.....	.....	.....	.....

For the rates of seeding tests at Morris, there is a rather uniform increase in yield averaging 12.6 bushels higher with no border rows removed as compared with yields when two rows were removed from either side of each plot. At University Farm the average increase was 10.8 bushels. When the outside border rows only were removed, the yields at Morris were from 1.7 bushels to 4.6 bushels higher than when both outside and inside borders were removed. At University Farm the removal of the outside border row appears to have done away with any border effect.

In the variety test at University Farm, in 1918, inclusion of the outside rows increased the yields of the oat crop 7.5 bushels, the wheat crop 4.4 bushels, and the barley 5.1 bushels. Including the three border rows on either side of each plot increased the yields of the oats 9.1, the wheat 5.7, and the barley 6.9 bushels. In 1917, the increases in yield due to border effect were still more marked.

On farms where crops are produced on fields of considerable size, border effect is negligible on account of the relatively small proportion of the field in border. Yields reported from plots, the borders of which have not been removed are therefore probably somewhat misleading, in that they are higher than those which would be secured from large fields under the same conditions. However, the more important consideration is the effect of borders on the relative yields of the different treatments in cultural tests and of the several varieties in tests of that nature.

The yields with the standard deviations and the rank at each rate of seeding for the oats at Morris and University Farm are given in Table VI.

TABLE VI.—*Comparison of average yields per acre from plots having alleys on sides and ends with no border rows removed, with one border row removed, and with two border rows removed from either side of each plot, for various rates of seeding of oats*

Location and rate of seeding (in pounds per acre).	Number of plots.	No border rows removed.			One border row removed.			Two border rows removed.		
		Yield per acre.	Rank.	Standard deviation.	Yield per acre.	Rank.	Standard deviation.	Yield per acre.	Rank.	Standard deviation.
Morris Substation:		*Bush.*			*Bush.*			*Bush.*		
48	3	48.0	5	6.45±1.78	40.7	5	5.52±1.52	36.8	5	6.78±1.87
64	3	54.0	4	.46± .12	44.7	4	1.10± .30	41.3	4	1.84± .51
80	3	59.9	1	2.49± .69	50.4	1	.98± .26	45.8	1	1.44± .40
96	8	58.7	2	5.93±1.63	48.9	2	6.57±1.81	45.4	2	7.31±2.01
112	3	55.0	3	4.46±1.23	45.1	3	5.75±1.58	43.4	3	7.73±2.13
Average		55.1		3.96	45.9		3.98	42.5		5.02
University Farm:										
48	10	80.4	5	7.03±1.66	72.0	4	7.64±1.15	72.3	4	7.97±1.20
64	10	80.5	4	5.77± .87	70.9	5	4.22± .64	72.2	5	3.84± .52
80	10	93.0	1	7.74±1.17	75.7	3	6.20± .94	76.1	2	7.66±1.16
96	10	88.8	2	7.33±1.11	79.5	1	6.89±1.04	79.3	1	7.72±1.17
112	10	86.9	3	5.24± .79	75.8	2	4.70± .71	75.5	3	4.98± .75
Average		85.9		6.62	74.8		5.93	75.1		6.43

Inspection of the yields from the various rates of seeding at Morris, with no border rows removed, show that the 80-pound seeding gave the highest yield and the others ranked in the following order: 96 pounds, 112 pounds, 64 pounds, and 48 pounds. This rank is not changed by the removal of one or two border rows. The least significant difference between the yields of any two rates of seeding was found for this test by using the formula

$$\frac{\text{standard deviation} \times 0.6745}{\sqrt{n}},$$

where n denotes the number of plots for each rate (*22*). The result was multiplied by 3.2, which makes the odds 30 to 1 that the result is not due to chance (*16*). For no border rows removed, this figure is 4.93. Where one and two border rows were removed, the figures are 4.96 and 6.27, respectively. If these are used in a broad way in the interpretation of the results, it appears that where no border rows were removed the 80-pound rate of seeding gave better results than the 64-pound rate, which in turn gave better results than the 48-pound rate. The interpretation of the results where one and two border rows were removed would not be much different.

At University Farm the rank with one and two border rows removed tends to be somewhat different than with no borders removed. Employing in a broad way 4.51, 4.06, and 4.38 bushels, respectively, as the least significant differences where none, one, and two border rows were removed, an interpretation of the results may be made. Where no border rows were removed, the 80-pound rate appears to have yielded the highest, with the 96-pound and 112-pound rates equal and in turn higher than the two lower rates. For the tests with one and two border rows removed, the 96-pound rate seems to have maintained a lead over the 80- and 112-pound rate and to have yielded significantly higher than the 64- or 48-pound rate of seeding.

The results for the variety tests of oats, wheat, and barley in 1918 with none, one, two, and three border rows removed are given in Table VII.

For the oat and barley varieties there are some changes in rank brought about by the removal of border rows. It is of interest to note that the removal of borders makes no change in the rank of the last four varieties, which were also the lowest in rank in the 1917 tests. In the barley variety test the rank of the Manchuria cross and the Chevalier are not changed. The Chevalier ranked the highest in 1917.

With the same formula as was used in the rate of seeding tests to secure figures representing the least significant differences, the following were secured for the oat tests: No borders removed, 5.26 bushels; one removed, 4.54 bushels; two removed, 4.46 bushels; and three removed, 6.90 bushels. These amounts have been subtracted from the

highest yielders under each method of test, and lines have been drawn at what may be considered the discard point for the season. Removal of one and three border rows, respectively, from either side of each plot lowers the discard point in the test. Due to the removal of the border rows, there are a number of changes in rank; but in general the varieties above the discard point with no border rows removed remain there under the other methods of test, except as has been previously noted.

For the wheat variety test the least significant differences in bushels per acre for the various methods of test are as follows: No borders removed, 1.67; one removed, 1.71; two removed, 1.92; three removed, 2.14. Lines have been drawn at what may be considered the discard point for the season. When no border rows were removed, Marquis gave a lower yield than Mindum or Preston; but with one border row removed from either side of each plot, Marquis equaled the other two in yield and maintained that rank with two and three border rows removed.

In the barley variety test the least significant differences were found to be for no border rows removed, 3.94 bushels; one row removed, 3.62 bushels; two rows removed, 3.58 bushels; and three rows removed, 3.97 bushels.

The removal of one border row from either side of each plot put the yield of one variety below the discard point adopted. The removal of three border rows put Svansota below the discard point. Removal of two border rows also raised Improved Manchuria from a rank of 6 to a rank of 4 in yield.

TABLE VII.—*Comparison of average yields per acre for 1918, for four $\frac{1}{40}$-acre plots (approximate size) with no border rows removed, and with one, two, and three border rows removed from either side of each plot for 14 varieties of oats, 7 varieties of wheat, and 9 varieties of barley*

Crop and variety.	Accession number.	Descriptive note.	No border rows removed.			One border row removed.			Two border rows removed.			Three border rows removed.		
			Yield per acre.	Standard deviation.	Rank.	Yield per acre.	Standard deviation.	Rank.	Yield per acre.	Standard deviation.	Rank.	Yield per acre.	Standard deviation.	Rank.
OATS.		Time of maturity:	*Bushels.*			*Bushels.*			*Bushels.*			*Bushels.*		
Lincoln	505	Medium	91.5	4.12±0.98	1	82.2	3.43±0.81	1	81.9	3.82±0.91	1	80.3	3.38±0.81	1
Selection [a]	358	do	90.2	6.55±1.56	2	81.8	5.36±1.28	2	79.8	5.33±1.27	2	77.2	6.28±1.50	6
Improved Ligowa [a]	281	do	88.8	8.16±1.95	3	80.1	7.67±1.83	3	78.8	8.43±2.01	4	78.7	9.31±2.22	3
Victory	314	do	88.1	1.59± .37	4	79.8	1.70± .41	4	79.0	2.07± .49	3	78.9	2.12± .51	2
Minota [a]	512	Medium early	87.7	8.48±2.02	5	79.1	8.75±2.09	6	78.3	9.04±2.16	5	78.1	9.27±2.21	4
Silvermine	506	Medium	86.9	3.84± .96	6	78.7	3.67± .88	7	79.8	1.08± .26	2	77.0	4.08± .97	7
Do. [a]	337	do	86.6	2.86± .68	7	79.4	3.00± .72	5	78.1	2.59± .62	6	77.4	2.56± .61	5
O. A. C. 72	500	do	[b] 86.1	2.05± .49	8	77.9	2.21± .53	8	[b] 77.3	1.42± .34	7	76.2	1.85± .44	9
Banner	507	do	85.7	3.19± .76	9	[b] 77.5	2.55± .61	9	76.9	2.92± .70	8	76.7	3.18± .76	8
Swedish Select	502	do	84.1	5.23±1.25	10	76.1	4.92±1.17	10	74.9	5.36±1.28	9	[b] 73.6	5.42±1.29	10
White Tartar	339	Late	76.8	8.53±2.03	11	69.8	2.42± .58	11	69.2	3.20± .76	10	68.4	2.93± .70	11
Iowa 103	531	Early	73.2	4.64±1.11	12	68.2	4.33±1.03	12	67.5	3.95± .94	11	67.3	4.17± .99	12
Kherson	261	do	71.6	5.64±1.34	13	66.2	5.76±1.37	13	66.2	5.50±1.31	12	65.9	5.92±1.41	13
O. A. C. 3	491	do	70.9	3.32± .79	14	66.2	3.14± .75	14	65.5	3.10± .73	13	64.9	3.44± .82	14
Average			83.4	4.87		75.9	4.21		75.2	4.13		74.3	6.39	
WHEAT.		Type:												
Mindum [a]	470	Durum	45.8	2.30±0.55	1	41.0	2.16±0.52	1	39.8	1.97±0.47	1	38.6	2.40±0.57	1
Preston [a]	924	*vulgare*	[b] 45.0	1.90± .45	2	39.6	1.94± .46	2	39.7	2.14± .51	2	38.2	2.44± .58	2
Marquis	1239	do	43.2	1.43± .34	3	[b] 39.2	1.93± .46	3	[b] 38.1	2.21± .53	3	[b] 37.7	2.35± .56	3
Preston×Preston [a]	188	do	41.5	0.16± .04	4	36.8	0.02± .00	4	35.7	0.50± .12	4	35.0	0.45± .11	4
Glyndon Fife [a]	163	do	38.7	1.96± .47	5	34.4	1.76± .46	5	34.2	1.81± .43	5	34.2	2.11± .50	5
Haynes Bluestem [a]	169	do	36.0	1.25± .30	6	32.4	1.43± .34	6	32.0	1.56± .37	6	32.0	1.68± .40	6
Acme	1967	Durum	35.2	1.84± .44	7	31.6	1.83± .44	7	30.9	2.26± .54	7	30.1	2.42± .58	7
Average			40.8	1.55		36.4	1.58		35.8	1.78		35.1	1.98	

BARLEY.															
		Type:													
Lion×Manchuria[a]	438	6-row smooth awn	64.3	4.35±0.10	1	60.0	4.02±0.10	1	58.9	3.76±0.90	1	58.8	4.00±0.95	1
Do	437	do	62.9	3.35± .08	2	59.3	3.25± .08	2	58.5	3.52± .83	2	[b] 57.6	3.68± .88	2
Svansota[a]	440	2-row *erectum*	61.0	6.15± .15	3	[b] 56.5	4.92± .12	3	[b] 55.3	4.93±1.18	3	53.9	4.63±1.10	3
Manchuria[a]	105	6-row common	[b] 60.7	1.66± .04	4	53.9	5.52± .13	4	50.7	1.13± .27	6	49.5	1.41± .34	7
Minsturdi[a]	439	True 6-row	59.3	5.78± .14	5	53.8	2.66± .06	5	52.1	5.20±1.24	5	51.3	7.37±1.76	6
Improved Manchuria[a]	284	6-row common	58.7	2.12± .05	6	52.9	1.70± .04	6	52.5	2.94± .70	4	52.5	3.31± .79	4
Manchuria×Manchuria[a]	390	do	57.2	2.65± .06	7	52.3	1.35± .03	7	52.1	2.08± .50	5	52.2	2.31± .55	5
Do[a]	388	do	45.0	4.38± .10	8	48.2	4.18± .10	8	46.6	4.02±1.00	7	46.1	4.19±1.00	8
Chevalier[a]	230	2-row *nutans*	46.4	2.43± .06	9	42.2	2.62± .06	9	41.5	2.30± .55	8	41.0	2.24± .55	9
Average			58.3	3.65		53.2	3.35		52.0	3.32		51.4	3.68	

[a] From the Plant Breeding Section, University Farm.

[b] Discard point for year.

SUMMARY AND DISCUSSION OF RESULTS

From the data given in Tables II and III, it appears that, subject to the influence of environment and varying somewhat with the crop, the effect of 18-inch cultivated alleys on the outside rows of plots is quite uniform and marked.

The effect on the second 6-inch drill rows within the border of the plots appears to be more variable. Thus, as shown in Table III, in the 1917 variety test, the effect ranged from 123.2 per cent in oats to 149.3 per cent in wheat and 150.3 per cent in barley, based on the average yields of the central rows. In the 1918 variety test, the second rows averaged 109.8 per cent for oats, 116.6 per cent for wheat, and 118.5 per cent for barley, based on the yields of the central rows. Considering the results for the rate of seeding tests at Morris, the second rows, inside border rows, yielded at the rate of from 152.7 per cent for the thinnest seeding to 123.0 per cent for the thickest, based on the yields of the central rows. The greatest border effect on the second rows appears to be in the thinnest-sown, and the least effect in the thickest-sown plots. In the rate of seeding test at University Farm there appears to have been no effect on the second rows.

The effect on the third rows, inside border rows of the 1918 test, was slightly less than the effect on the second rows for each crop. They yielded at the rate of 106.1 per cent for oats, 113.7 per cent for wheat, and 108.6 per cent for barley, based on the yields for the central rows as 100.

Therefore, in this test with varieties of oats, wheat, and barley, the influence of 18-inch cultivated alleys extended to the third 6-inch drill rows within the plots on either side. When sown at this distance apart, the third drill rows occur at a distance 15 inches from the outside boundaries of the plots. Possibly the differences in the crops grown and in the environment may account for the influence of the borders being exerted to a greater distance within the plots than was observed by Bedford and Pickering (*3*). In their tests it is not stated whether a crop was growing on the other side of an alley or whether the rows were bordered by a considerable fallow space. A considerable fallow area presumably would exert an influence farther within a plot than a narrow cultivated alley flanked on the other side by the same crop.

Bedford and Pickering (*3*) found it necessary to make the outside rows, since the actual outside rows were often found to be so badly injured by the cultivating implements as to be unfit for use. In the absence of any statement on this matter, it is presumed that the rows of plants were removed from the plots very early before the root systems had become moderately well established. Otherwise the border effect may have been modified considerably by the growth of the plants before removal and later by the presence of the decaying roots in the soil.

It is not within the scope of this paper to discuss in any detail the reasons for border effect; but, from the greater effect in the thickness of seeding test at Morris in 1918 under comparatively dry conditions both on the first and second rows in the plots as compared with the results at University Farm, where favorable moisture conditions prevailed, it seems reasonable to assume that increased moisture supply with accompanying results probably is one of the prominent factors.

As to the effect of border rows on the interpretation of results, it has been shown that (1) where they are not removed the yields of plots are higher than where these rows are eliminated before harvest and (2) the rank of a variety or of a rate of seeding in relation to the discard point derived for the particular test may change on account of the removal of border rows.

If the only effect of border rows lay in increasing yields beyond what would be secured in large fields under like conditions, the expense of removal of borders would probably not be warranted. However, when the interpretation of the results, as has been brought out in Tables VI and VII and in the results for the 1917 variety tests (*2*), is necessarily different in some instances when the yields with the border rows is considered than when they are removed, the matter warrants very careful consideration. It is of interest to note in this connection that the removal of the border rows did not necessarily reduce the probable error in the tests.

When border rows are removed, the question arises as to how many. From the 1917 results (*2*) it seemed desirable to remove two border rows. In the 1918 tests, the effect on the second rows at Morris is very marked and in this respect is similar to the results with the varieties at University Farm in 1917. At University Farm, the effect on the second rows in the variety tests in 1918 is less marked than in the same tests in 1917, but the effect is shown to extend definitely to the third rows. In the rate of seeding test with oats there was practically no effect on the second rows.

From the data given, unless border effect can be prevented in some other way, it appears advisable as a precaution to insure the most reliable results to remove at least two 6-inch border rows from either side of grain plots bounded by alleys or roadways.

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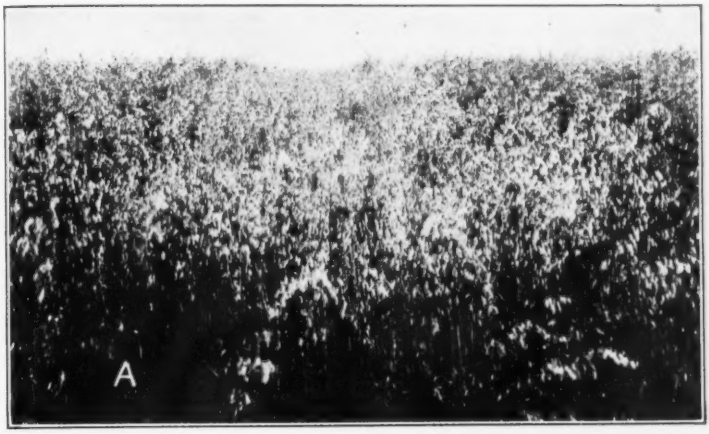
PLATE 94

Border effect shown in the experiment on rate of seeding of oats at Morris in 1918.
A.—Oats sown at rate of 48 pounds per acre.
B.—Oats sown at rate of 96 pounds per acre.
C.—Oats sown at rate of 112 pounds per acre.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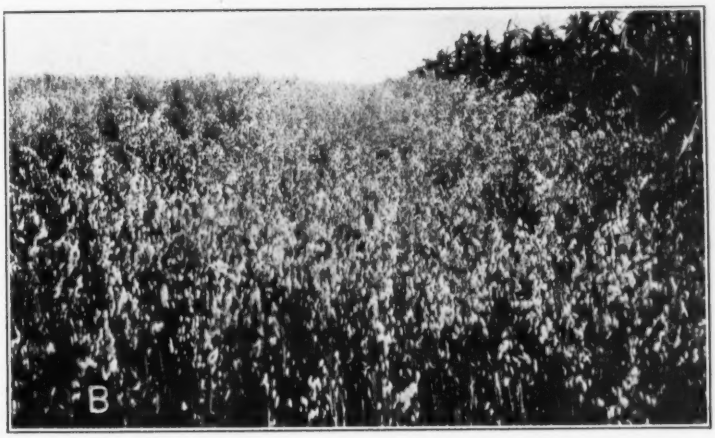
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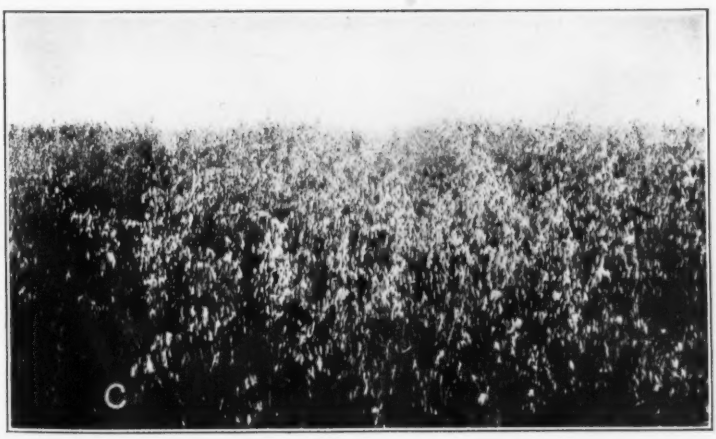
C

RELATION OF HORSE NETTLE (SOLANUM CAROLINENSE) TO LEAFSPOT OF TOMATO (SEPTORIA LYCOPERSICI)

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INTRODUCTION

Horse nettle (*Solanum carolinense* L.), a weed closely related to potato and tomato and generally distributed in fields and waste places from Ontario to Massachusetts, Florida, Illinois, Nebraska, and Texas, has been found to be a host of the tomato leafspot, or blight, fungus.

In Maryland, New Jersey, and Delaware, where tomato leafspot causes heavy annual losses, horse nettle (Pl. 95, 96) is very common in waste places, in grass and grain fields, and even in cultivated crops. Its numbers in fields of tomatoes in the Middle Atlantic States, especially in Delaware, not infrequently exceed those of the tomato plants 5 to 20 times. Moreover, it bears numerous spots (Pl. 97, A) which in size, shape, color, and other appearances closely resemble leafspot of tomato (Pl. 98, A). Observations of these facts caused the writers to determine whether or not horse nettle is a host of the tomato leafspot fungus.

EXPERIMENTAL WORK

MATERIAL AND METHODS

Young tomato and horse nettle plants were grown from seed in the greenhouse and used for inoculation when 1 to 5 inches high. Considerable difficulty was at first encountered in germinating the horse nettle seed, but this was finally overcome by setting the seed pots directly on the steam pipes. Both the tomato and horse nettle seedlings were in a thrifty condition when inoculated. Control plants were used in approximately as large numbers as inoculated plants in each experiment.

The inoculations were made by spraying the plants with spores from a pure culture by means of either a DeVilbiss atomizer or a small spray pump, or by transferring minute pieces of mycelium from a rapidly growing culture to leaves moistened with distilled water. Both the inoculated plants and the controls were kept in a moist chamber 48 to 60 hours and then transferred to benches in the greenhouse.

INOCULATION OF HORSE NETTLE PLANTS WITH SEPTORIA LYCOPERSICI FROM TOMATO

In the fall of 1919 about 25 horse nettle plants transferred from the field to the greenhouse and inoculated with a pure culture of *Septoria lycopersici* Speg obtained from tomato became infected with numerous

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spots resembling leafspot of tomato, while an equal number of horse nettle plants not inoculated but kept in the same environment as the inoculated plants remained healthy. During the winter of 1919–20 more than 500 horse nettle seedlings 1 to 5 inches high were inoculated with this fungus, and as many more were used as controls. The leaves of about 90 per cent of the inoculated plants became infected, but not one of the control plants showed any symptoms of the disease.

The culture used in making these inoculations was isolated from a Septoria spot on a tomato leaf and had been used to infect several thousand tomato seedlings. In morphology, in growth on standard culture media, and in development on tomato leaves it was typical for *Septoria lycopersici*.

The horse nettle leafspots (Pl. 99, A) when small were usually somewhat circular in outline and brown in color, but when older they became more irregular in outline, light-colored in the center and dark at the margins. There is a larger percentage of circular spots in Plate 99, A (artificially infected leaves) than in Plate 97, A (naturally infected leaves); but this is due largely, if not wholly, to the fact that the spots in Plate 99, A, are younger than those in Plate 97, A. The larger spots in both plates are more or less irregular in outline. In fact, the shape of the spots on tomato leaves (Pl. 98, A) varies from a circular form when small to a more or less irregular outline when large.

The horse nettle seedlings were not quite so susceptible to the leafspot fungus (*Septoria lycopersici*) as tomato seedlings. They showed more individual variation in resistance but became infected readily and became fairly thickly covered with spots (Pl. 99, A).

The spots on the horse nettle leaves infected in the greenhouse differed somewhat from those on the tomato leaves in pycnidia production. Pycnidia appeared on nearly all the spots on tomato leaves but only on a relatively small percentage of the spots on horse nettle leaves. They were usually numerous on this small percentage of horse nettle spots but were more deeply imbedded than on tomato leaves and were not always easily seen without the aid of a hand lens. The appearance of both the spots and pycnidia on tomato and horse nettle leaves may be seen in Plates 97, B; 98, B; 99, B, C.

The pycnidia on the horse nettle leaves produced innumerable spores which where indistinguishable from those taken from tomato leaves. Both the pycnidia and spores in mass are shown in a section of horse nettle leaf in Plate 99, B, C. Many of the pycnidia were even more deeply imbedded than the pycnidium shown in Plate 99, B, which in surface view was not very conspicuous to the unaided eye.

Since pycnidia of *Septoria lycopersici* developed rather sparingly on horse nettle leaves in the greenhouse, 222 horse nettle plants inoculated with a culture of *S. lycopersici* obtained from tomato were planted outdoors where the air was supposedly drier; but only a few scattered pycnidia developed on these plants until nearly the end of the growing

season. They were then found chiefly in small, dark brown spots lying in large dead areas near the tips and edges of the leaves. As pycnidia did not appear on tomato leaves in the field until very late in the fall, it is quite possible that the very wet weather during August hindered their development on both tomato and horse nettle. In fact it has been repeatedly noted while working with this fungus, both in the greenhouse and in the field, that the development of pycnidia on tomato plants is favored by dry air and hindered by moist air. This variability in sporulation occurs also on culture media. The drier areas in corn meal cultures of *S. lycopersici* develop pycnidia readily, while those that are moist produce them only after the medium becomes somewhat dry or not at all.

INOCULATION OF TOMATO AND HORSE NETTLE SEEDLINGS WITH SEPTORIA LYCOPERSICI REISOLATED FROM HORSE NETTLE LEAVES

Thirty young tomato plants and 14 young horse nettle plants 3 to 6 inches tall were inoculated by spraying their leaves with spores of a culture of *Septoria lycopersici* reisolated from horse nettle. Twenty uninoculated tomato plants were sprayed with distilled water and used as controls. Both the inoculated plants and the control plants were kept in a moist chamber 60 hours.

All the tomato and horse nettle plants became heavily infected, but none of the controls developed any symptoms of the disease. Pycnidia developed on the spots, but they were much more common and more conspicuous on the tomato than on the horse nettle. The spores, which developed in profusion, were identical in shape and size with those produced by the original culture obtained from tomato.

SEPTORIA ON NATURALLY INFECTED HORSE NETTLE

Spots resembling leafspot of tomato began to appear on horse nettle leaves at the Arlington Experimental Farm and in fields and gardens in the vicinity of Washington about the middle of August but bore very few if any pycnidia before the middle of September. This was approximately coincident with the appearance of pycnidia of *Septoria lycopersici* on tomato leaves.

The pycnidia found on naturally infected horse nettle leaves after the middle of September were rather numerous but appeared on only about 1 per cent of the spots. They contained innumerable spores that were indistinguishable morphologically from those of the tomato leafspot fungus, *Septoria lycopersici*. Dead areas near the tips and margins of the leaves seemed to afford the most favorable conditions for their development, for they were found most frequently within these areas.

Several attempts were made to isolate a pure culture of the Septoria from naturally infected horse nettle leaves by use of the spores, but in each case the spores failed to germinate. The writers were not surprised at these results, however, as it often requires repeated efforts to isolate

a culture of *Septoria lycopersici* from tomato leaves even when spores are used. Moreover, it is still more difficult to isolate Septoria from minute pieces of infected tissue, such as may be obtained from spots on tomato leaves, because these infected tissues are nearly always invaded by other organisms, and a treatment that will kill these accompanying organisms will kill Septoria. As Septoria grows very slowly in culture other organisms, if present, soon prevent its development by growing over the surface of the culture medium. It is very likely that Septoria could have been isolated from these naturally infected horse nettle leaves about as easily as from tomato leaves, however, had not a frost defoliated the plants when the plating of the spores was started and made it almost impossible to find more spore-bearing material.

ISOLATION OF ORGANISMS OTHER THAN SEPTORIA FROM LEAFSPOT OF HORSE NETTLE

While looking for pycnidia of Septoria on naturally infected horse nettle leaves, the writers observed a Phoma, an Alternaria, and two species of Cladosporium fruiting on the surface of the dead spots. One Cladosporium resembled *Cladosporium fulvum* Cke. in the shape of its spores and in the production of a purple color on both cornmeal and oatmeal agar but differed from it in the production of smaller spores.

The pathogenicity of each of these fungi was tested in four to five series of experiments by inoculating with a pure culture thrifty young tomato and horse nettle seedlings and keeping them in a moist chamber 48 to 60 hours after inoculation. No spots resembling those occurring naturally on horse nettle or those produced by spraying horse nettle or tomato plants with spores of *Septoria lycopersici* developed on any of these plants. Seven out of 100 tomato plants inoculated with the Alternaria developed an infection spot, but it was an elongated area following the veins and was found also on a few uninoculated plants of the same age on the greenhouse benches. Moreover, it did not appear on horse nettle. It would therefore seem that the four fungi isolated from horse nettle leafspots were merely saprophytes.

DISCUSSION

Septoria lycopersici is a very active parasite. It readily infects all the varieties of tomatoes grown in the United States and all varieties, both wild and cultivated, that the writers have been able to obtain through the Office of Seed and Plant Introduction. It infects very easily *Cyphomandra betacea* Sendt., the tree tomato, and a species of Solanum from Ecuador, *Solanum mammosum* L. On this Solanum it also produces numerous pycnidia and spores. It is not surprising, therefore, that it infects *Solanum carolinense*.

Since *Septoria lycopersici* in pure culture infected horse nettle seedlings readily and developed pycnidia and spores both in the greenhouse and outdoors, it is apparently able to maintain itself on this host. The

Septoria pycnidia found on naturally infected horse nettle were probably also those of *S. lycopersici*, since they were similar to them in size, form, and spore contents and developed on approximately the same percentage of spots as the pycnidia on the artificially infected horse nettle plants.

It is very likely that in the Middle Atlantic States most if not all the horse nettle leafspots resembling tomato leafspot are caused by *Septoria lycospersici*. The fact that *S. lycopersici* infects horse nettle easily and produces spots, pycnidia, and spores that can not be distinguished morphologically from those occurring on horse nettle in the field would tend to support this conclusion. Moreover, it would also seem to be strengthened by the failure of the other organisms isolated from these spots to reproduce the leafspot disease.

The results of the inoculations with a pure culture of *Septoria lycopersici* show that horse nettle is a very susceptible host for this parasite. It should therefore be kept out of prospective tomato fields to prevent its harboring the tomato leafspot fungus and thereby largely destroying the benefits that would otherwise be secured from rotation of crops. For the same reason it should be destroyed in fence rows, roadsides, and other waste places near tomato fields

SUMMARY

Horse nettle, a weed common in fields and waste places in the eastern half of the United States, usually bears in the Middle Atlantic States numerous spots on its leaves resembling leafspot of tomato. Inoculation of more than 500 horse nettle seedlings with a pure culture of the tomato leafspot fungus, *Septoria lycopersici*, caused infection of about 90 per cent of the plants, while an equal number of controls remained free from the disease. The spots closely resembled those occurring naturally on tomato and horse nettle.

Pycnidia developed rather freely on about 1 per cent of the spots on the inoculated horse nettle plants both in the greenhouse and outdoors. The pycnidia and spores were indistinguishable from those of *Septoria lycopersici* on tomato.

A culture of Septoria reisolated from the artificially infected horse nettle plants produced on both horse nettle and tomato leaves spots, pycnidia, and spores typical for *Septoria lycopersici*.

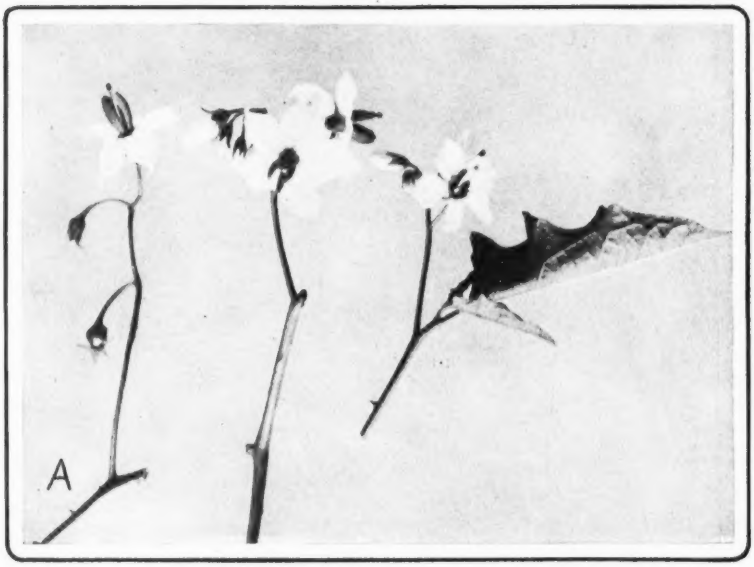
Pycnidia and spores of a Septoria identical in appearance with *Septoria lycopersici* were found on naturally infected horse nettle leaves late in the fall.

A Phoma, an Alternaria, and two species of Cladosporium were found fruiting on horse nettle leafspots, but repeated efforts to reproduce the spots with pure cultures of these fungi ended in failure. It is therefore likely that in the Middle Atlantic States most, if not all, these spots resembling leafspot of tomato are due to *Septoria lycopersici*.

PLATE 95

A.—Horse nettle plant growing in a field of tomatoes.
B.—Horse nettle plants growing on the bank of a drainage ditch.

A
B


A

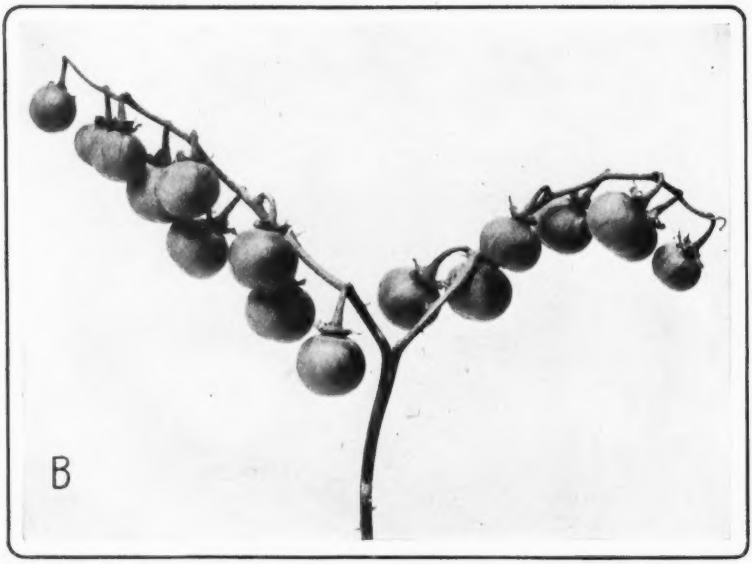

B

PLATE 96

A.—Flowers of a horse-nettle plant. Note their similarity to the flowers of potato and tomato. Some horse nettle plants have white flowers and others blue. × 2/3.

B.—Fruit, or seed balls, of a horse-nettle plant. Note their resemblance to the seed balls of potato. × 2/3.

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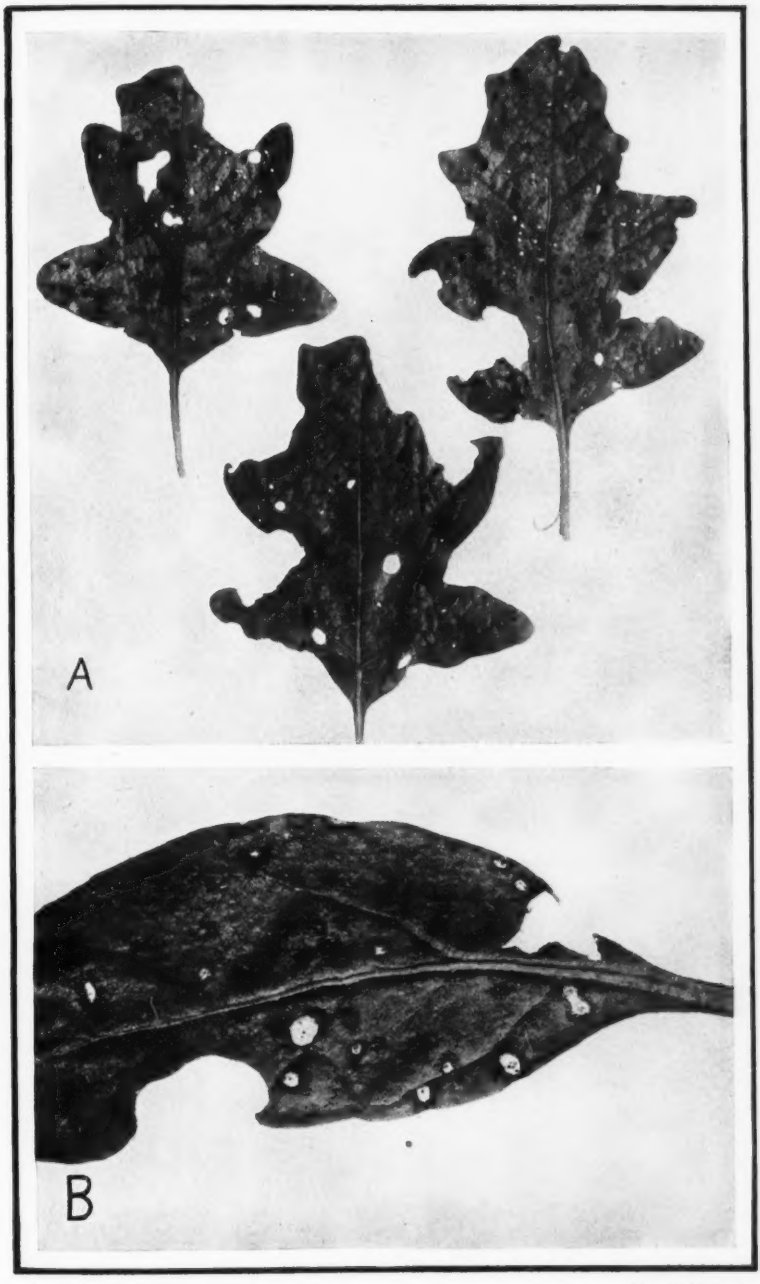
PLATE 97

A.—Leafspot of horse nettle. Natural infection. Slightly reduced.

B.—Leafspot of horse nettle produced by inoculation with a pure culture of *Septoria lycopersici* from tomato. Enlarged to show pycnidia, which are partially embedded in the tissues of the spots. × 3.


A
B

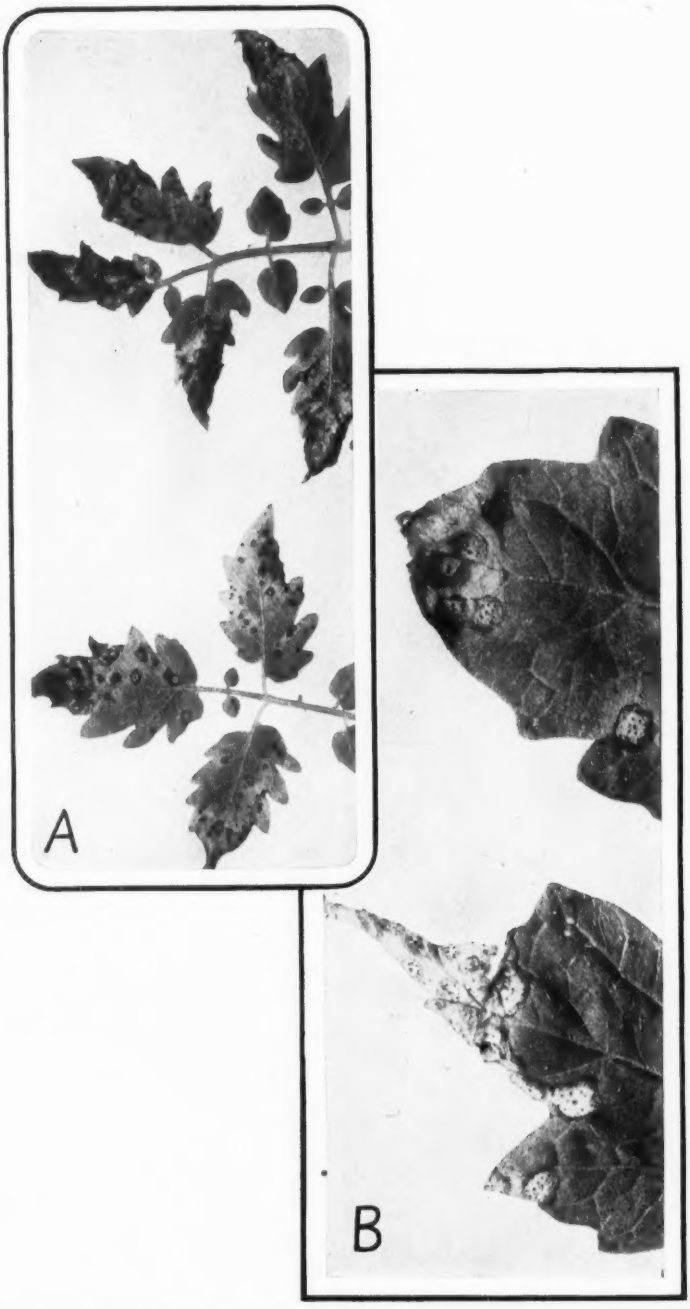

A
B

PLATE 98

Leafspot of tomato (*Septoria lycopersici*).
A.—Slightly reduced.
B.—Enlarged to show pycnidia. × 3½.

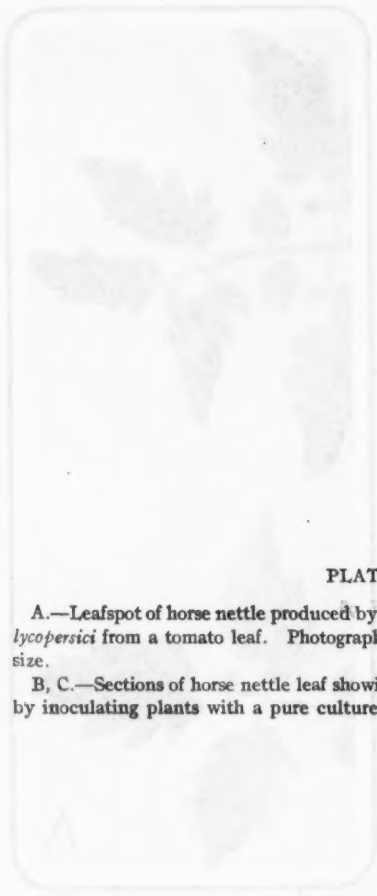
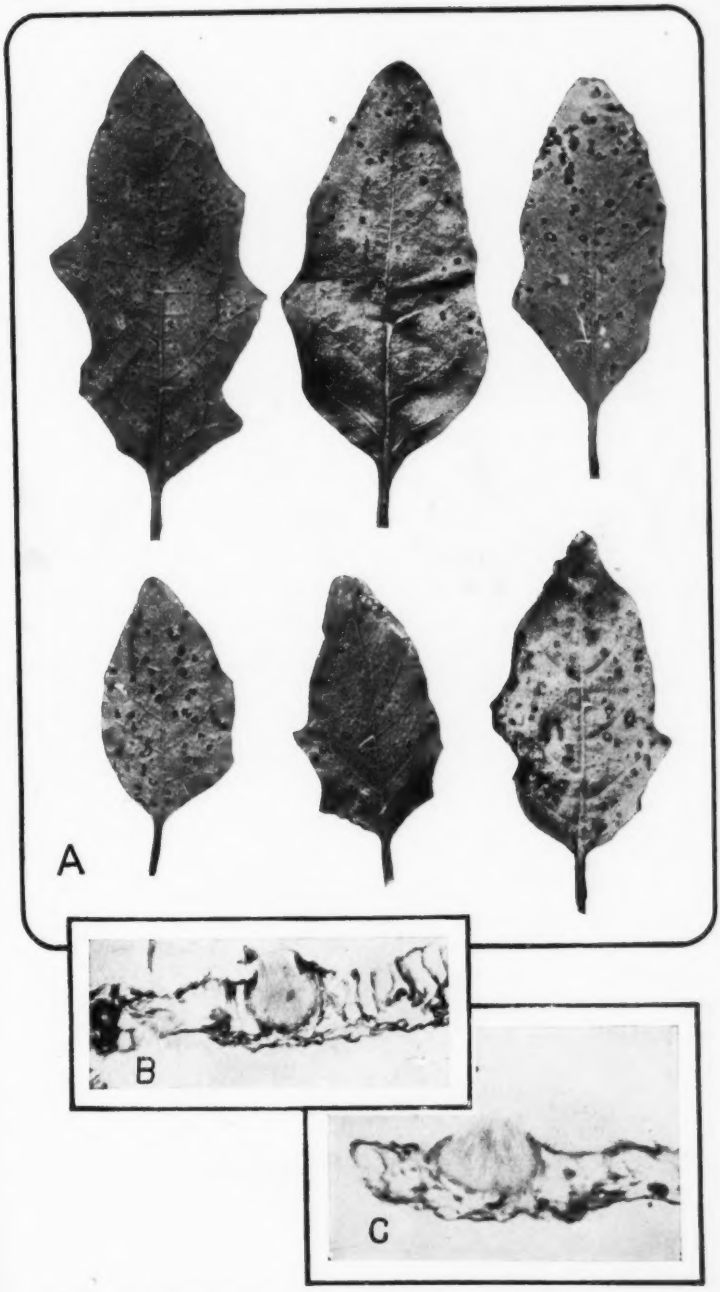


PLATE 99

A.—Leafspot of horse nettle produced by inoculation with a pure culture of *Septoria lycopersici* from a tomato leaf. Photographed two weeks after inoculation. Natural size.

B, C.—Sections of horse nettle leaf showing pycnidia and spores in mass, produced by inoculating plants with a pure culture of *S. lycopersici* from tomato.


A
B
C